CONTROL ASPECTS OF FLYING WINGS
WITH AFT - & FORWARD- SWEEP, Camber & Twist

Dr. R. K. Nangia

Bsc PhD CEng AFAIAA FRAeS

Nangia Aero Research Associates,

BRISTOL, UK.

	Report Documentation Page		Form Approved OMB No. 0704-0188

1. REPORT DATE **26 JUL 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **Control Aspects Of Flying Wings With Aft - & Forward- Sweep, Camber & Twist**		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Nangia Aero Research Associates, BRISTOL, UK.**		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES **See also ADM001685, CSP 02-5078, Proceedings for Aerodynamic Issues of Unmanned Air Vehicles (UAV)., The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**37**	

ACKNOWLEDGEMENTS

- The work mentioned here is part of in-house R & D activities.

- Have pleasure in acknowledging helpful technical discussions with Mr. Les Hyde, Mr. John Hall & Dr. Mike Palmer.

- Lastly it should be mentioned that any opinions expressed are those of the author.

Introduction

- Revival of Interest in Flying wings, Military & Civil
- More Efficient ? More "Twitchy"
- Northrop B-2 & McDonnell Douglas (Boeing) Studies
- Some Commonality, Apart from STEALTH
- Short Moment arms & Low Inertia in Pitch

- Design for Well Behaved Pitch behaviour at all speeds & Cross-wind ability
- Intake, Propulsion Integration varies with Application

No Winglets

No Fins

Northrop B-2, Essentially Optimised for Cruise

Military Flying Wings

Boeing (McDonnel Douglas)
Liebeck & Others
Transport/Civil Flying wing
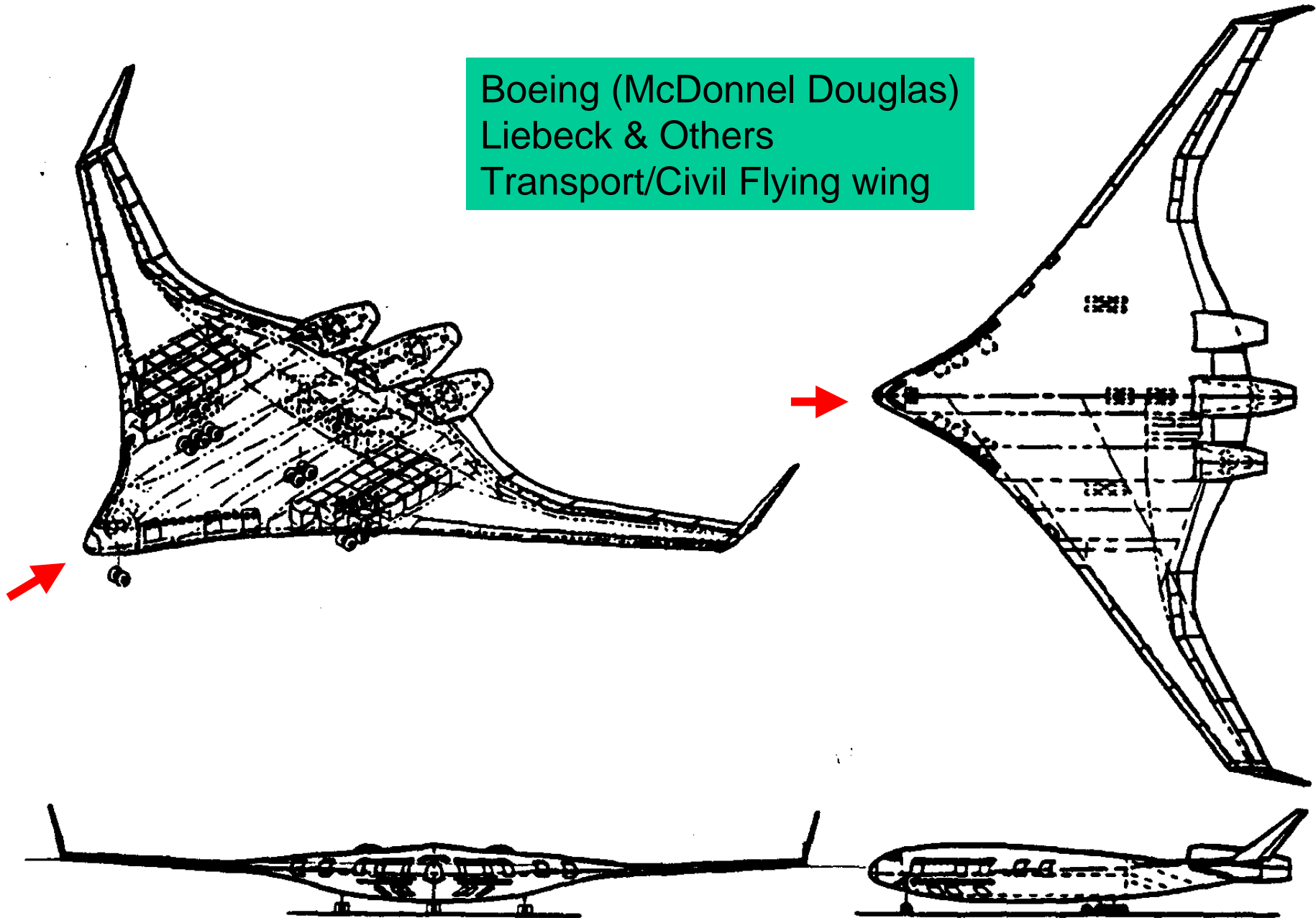
This Presentation

- Based Originally from a Civil Viewpoint

- Flying Wings have:

- Special set of Different Constraints vs Conventional

- Consider Planforms Aft- & Forward- Sweep

- Stability & Control Important

  – Design of Camber & Twist, Mach no divergence

  – Low speed & high speed neutral points

  – Floor angle

- Address Lateral & Directional Issues

- Avenues for Further Work
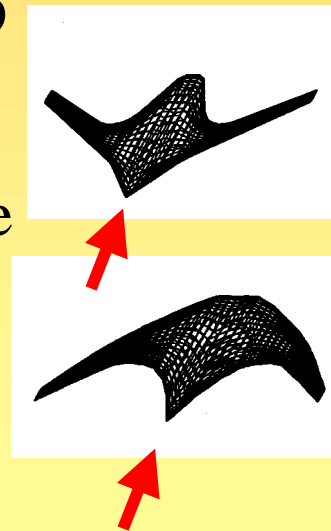
Approach: Subsonic Theory & Euler

- Lifting Surface, Vortex Lattice Theory
  - first-Order Mach no Effects
- Attained Thrust & Vortex Estimates

- We tend to focus on S & C aspects first
  - longitudinal , Directional & Lateral Trim
  - Cruise & Field Performance
- Then detail design using Panel, CFD
  - Aerofoils, Shocks & Tailoring

Variation

Variation

Variation
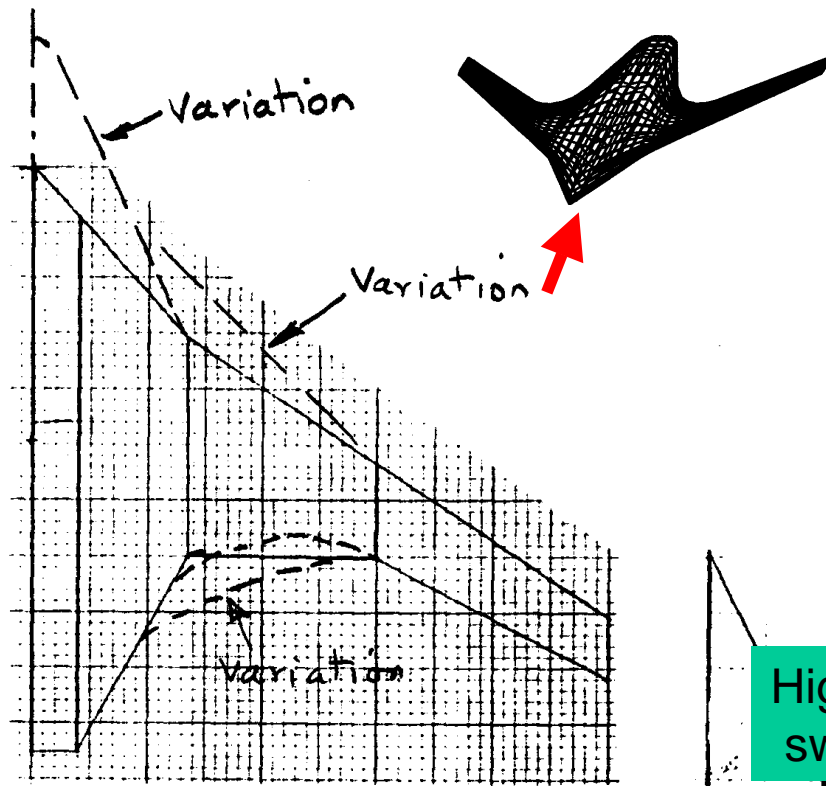
ASW -A1
wing fw'd
on inner wing

Current Planform Studies
Many Feasible
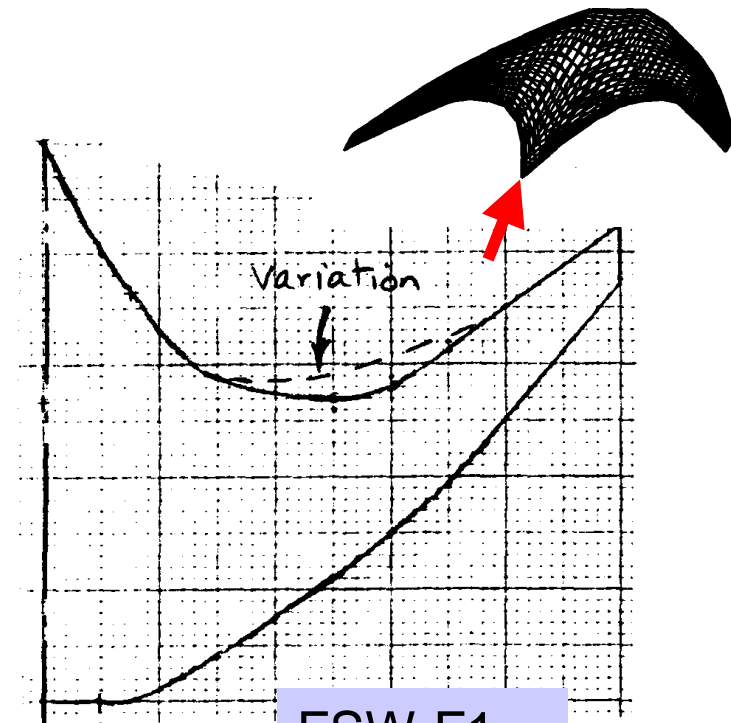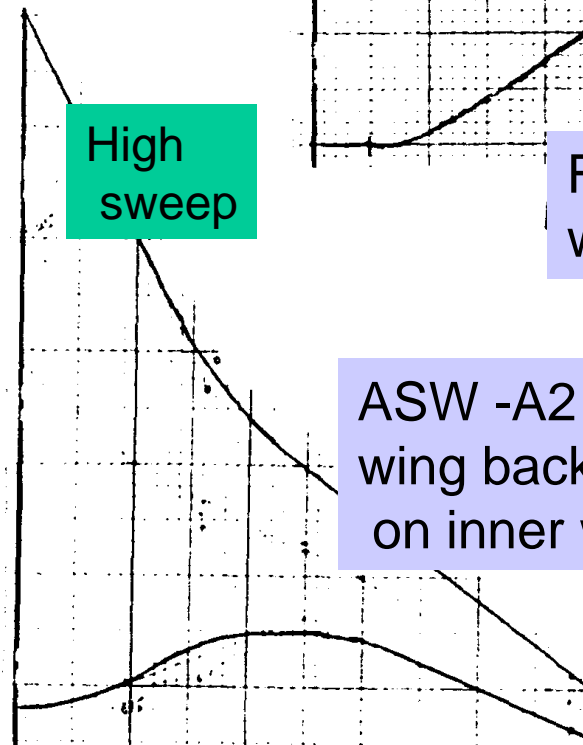
High
sweep

ASW -A2
wing back
on inner wing

Variation

FSW-F1
wing back

Design Envelope
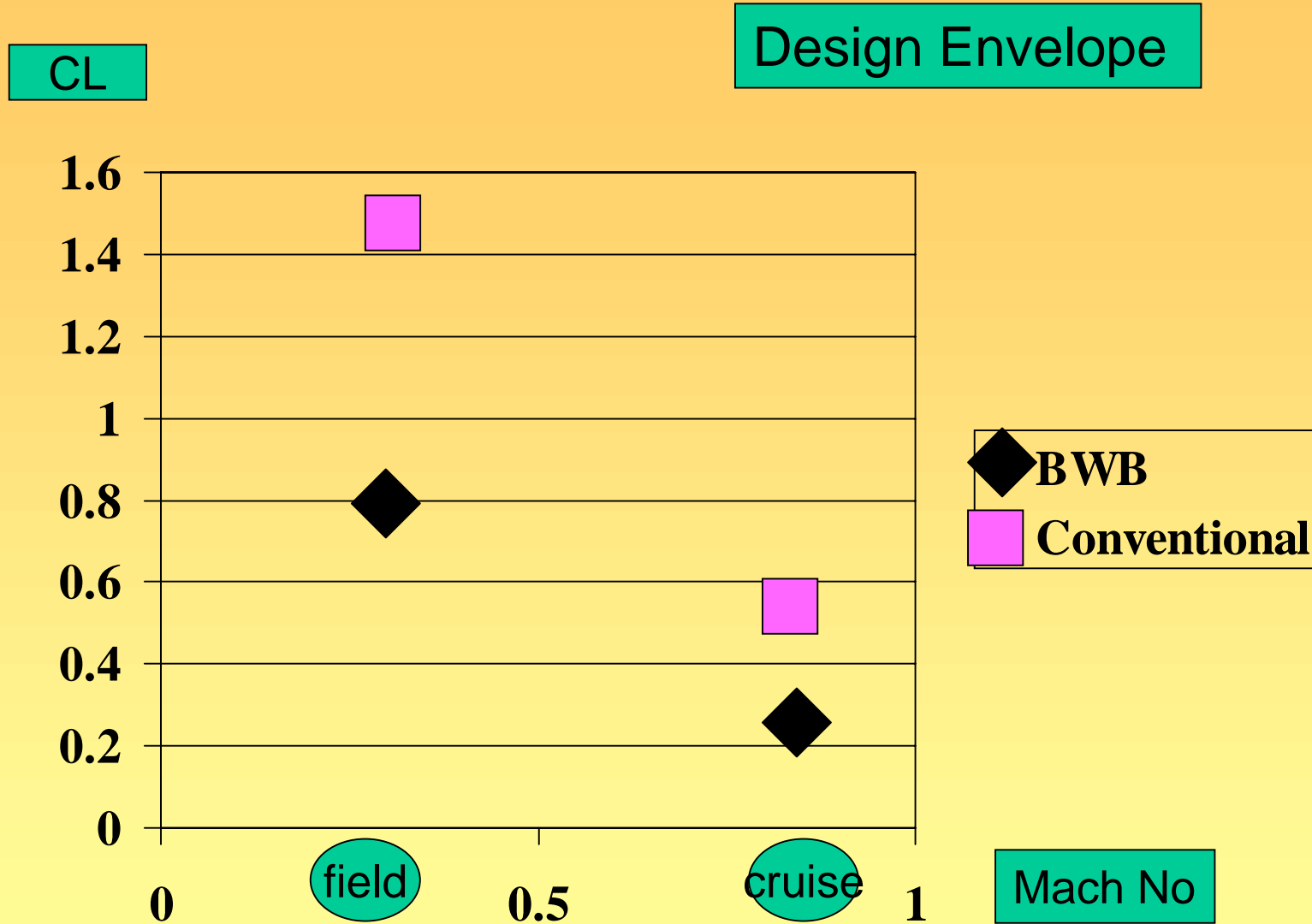
Practical "Highly" Swept Wings/portions at high lift

- Cranked LE poses difficulties
- local CL's high
- Use attached flows as far as possible (L/D)
- Use LE/TE devices, if possible !
- Need to understand Vortex Breakdown enough to control it or design around it
- Multiple vortex fields exist, "peeling" off
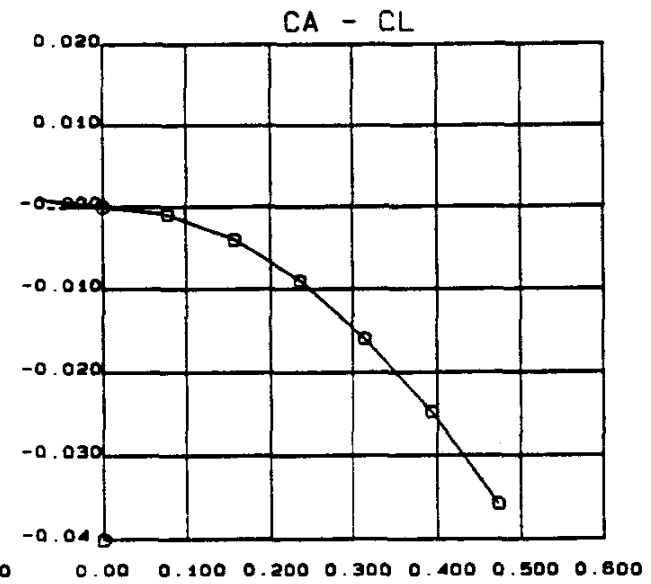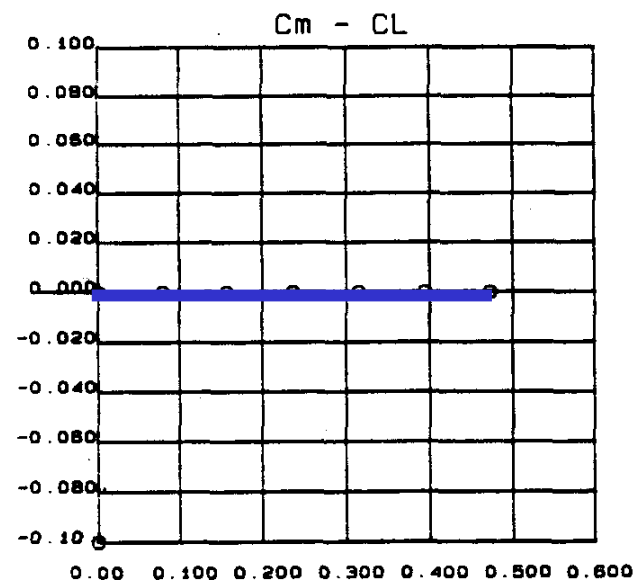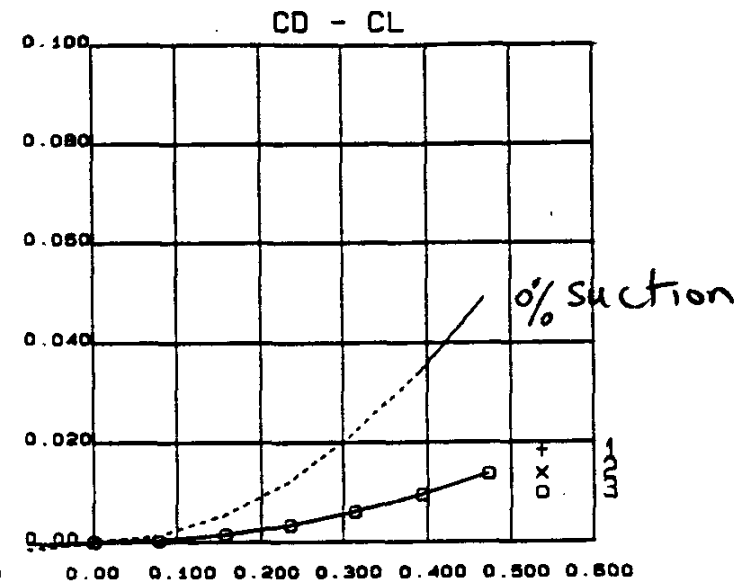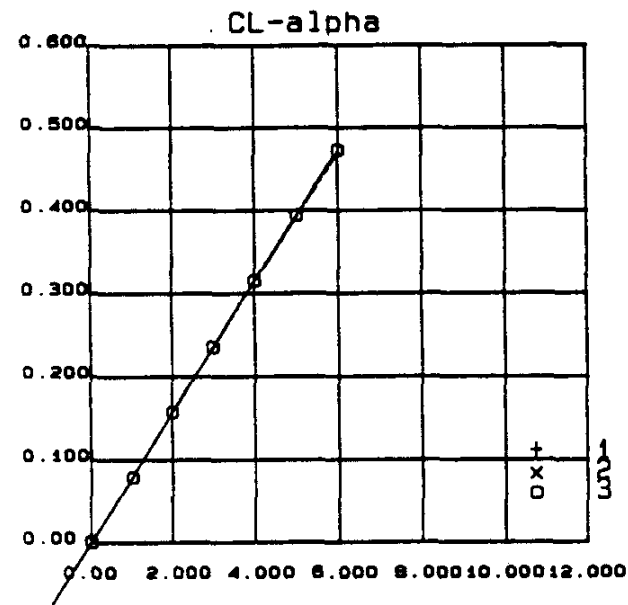
CL-alpha

CD - CL

0% suction

Cm - CL

CA - CL

About
Neutral point

ASW -A1   PLANAR, FORCES & MOMENTS, Mach 0.8
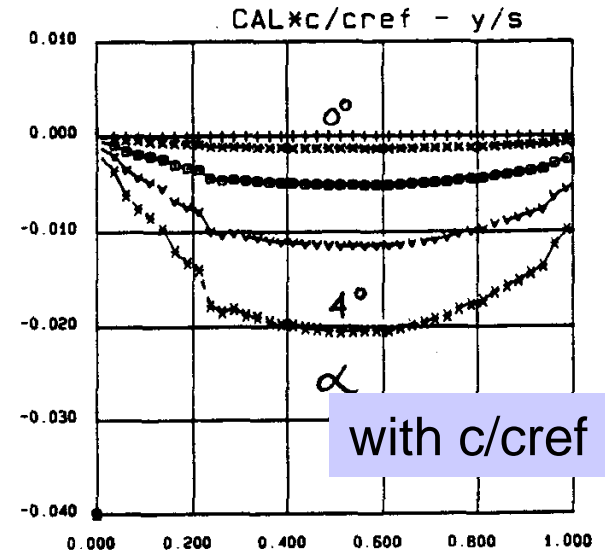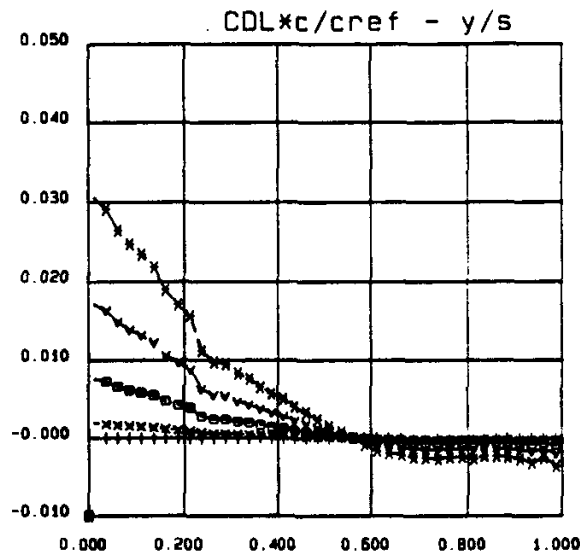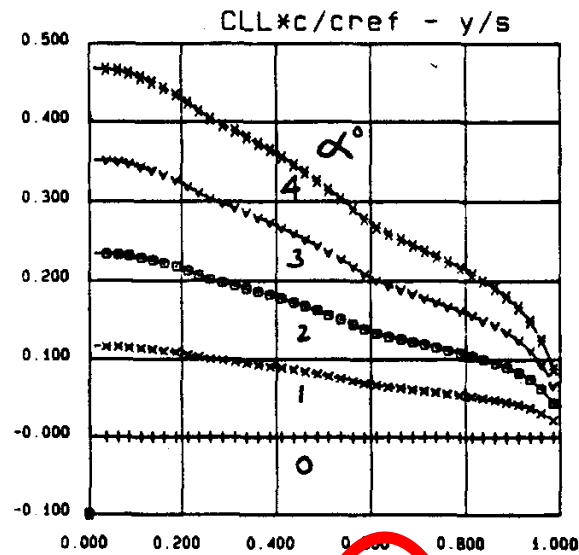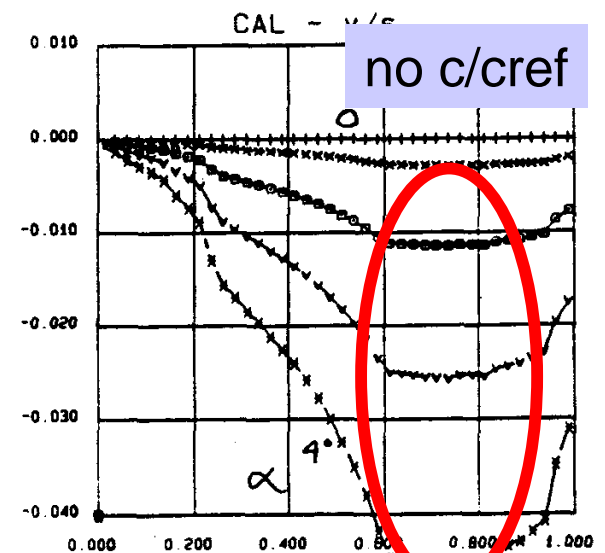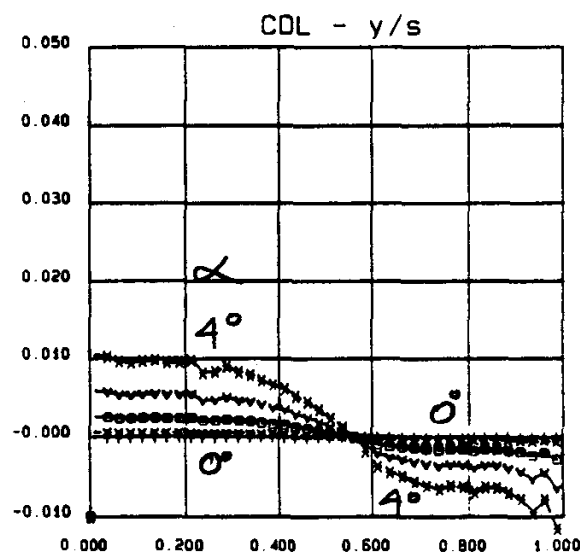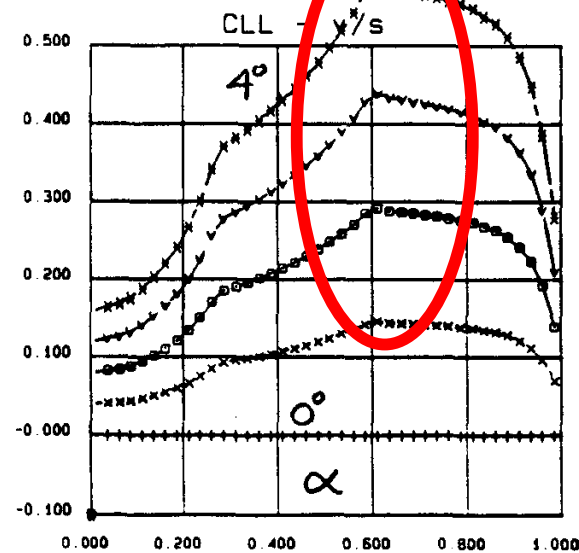
PLANAR, SPANWISE LOADINGS WITH AOA VARIATION, LIFT, DRAG & AXIAL FORCE, Mach 0.8

ASW -A1

CLL*c/cref - y/s   CDL*c/cref - y/s   CAL*c/cref - y/s

drag

STABLE

DESIGNED with c/cref

NEUTRAL

UNSTABLE

thrust
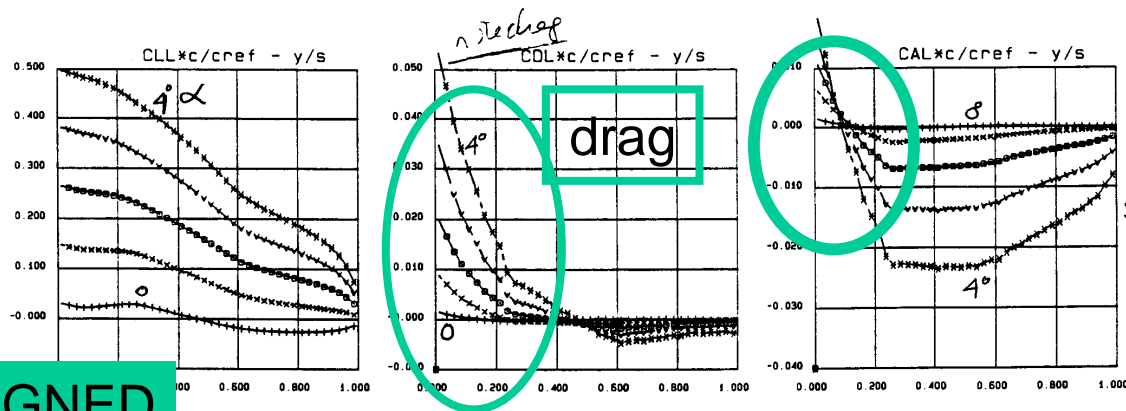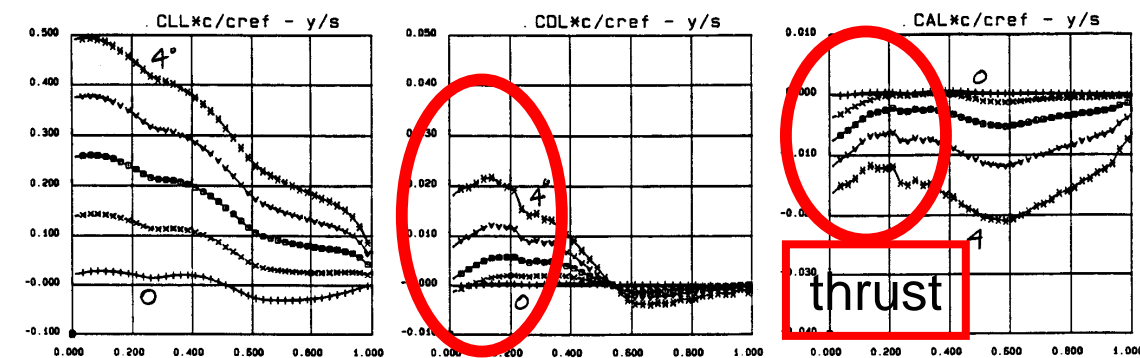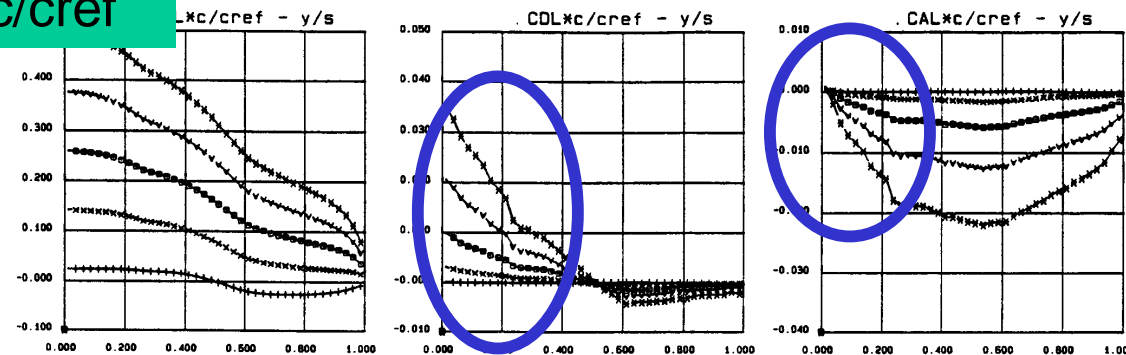
ASW -A1

PLANFORM A1, DESIGNED CAMBER, SPANWISE LOADINGS WITH c/c_{av} FACTOR, STATIC MARGIN VARIES, 10%c_{av} Stable, Neutral & 10% c_{av} Unstable, Mach 0.8
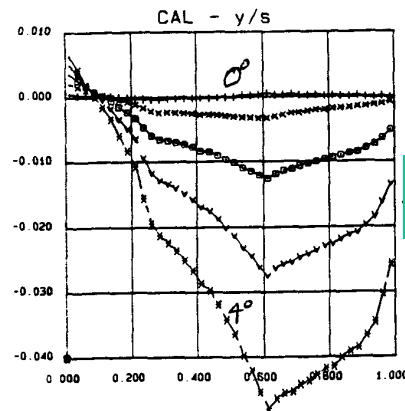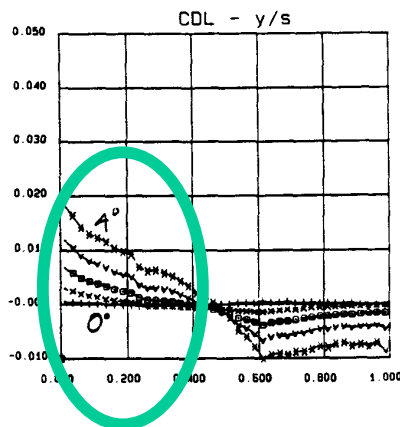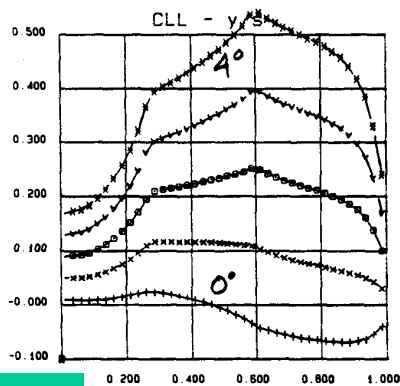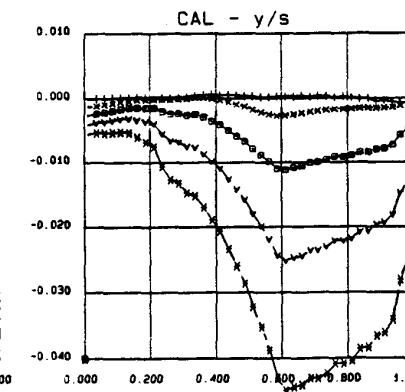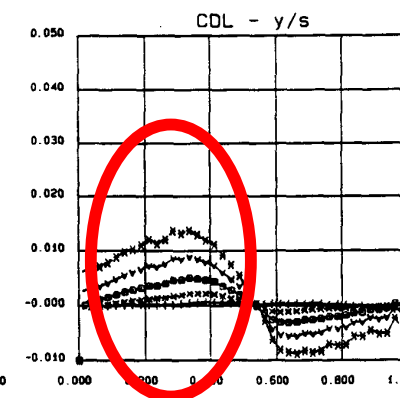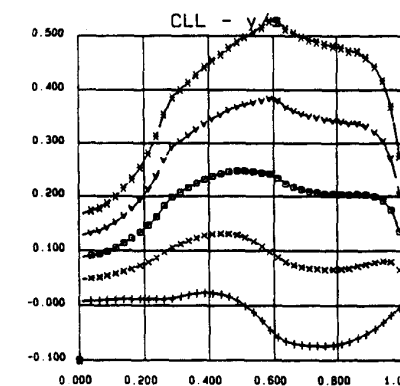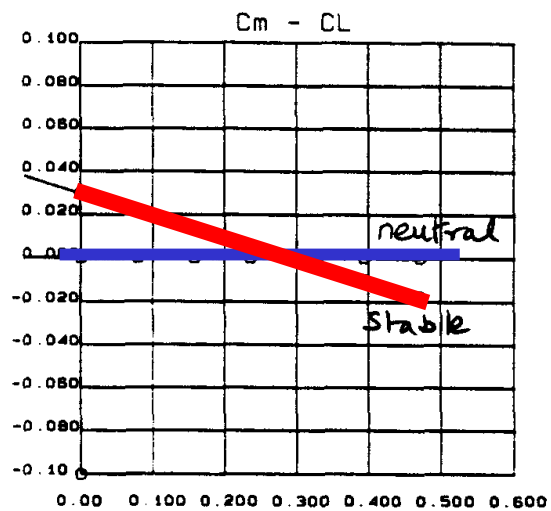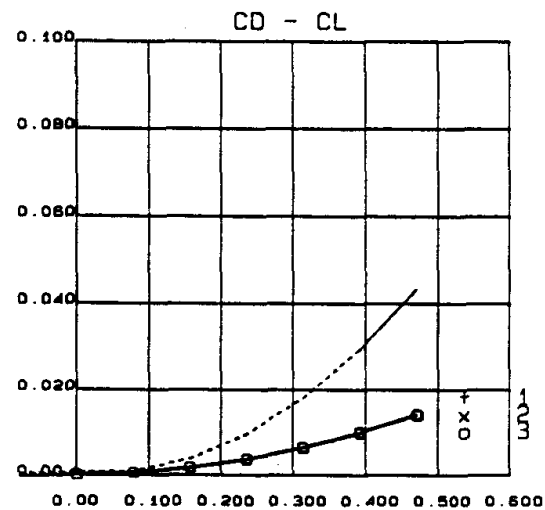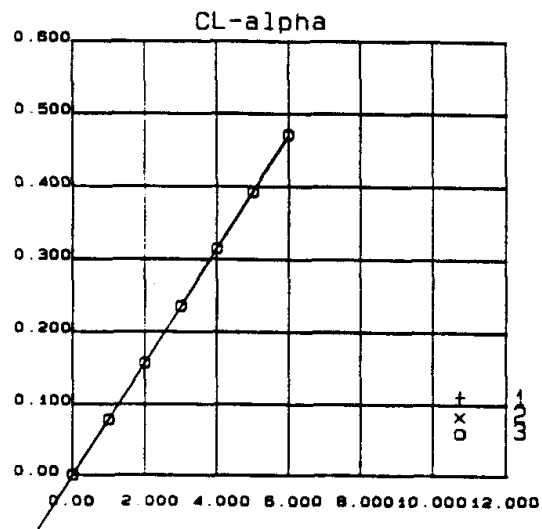
STABLE

DESIGNED
no c/cref
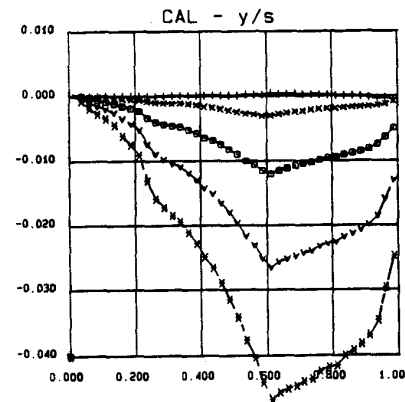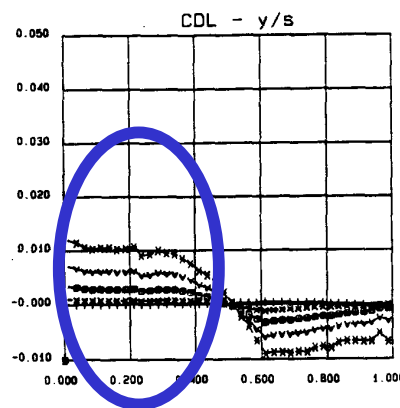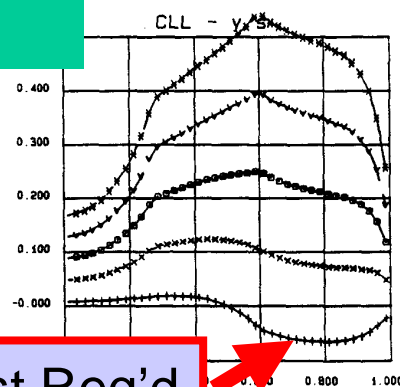
NEUTRAL
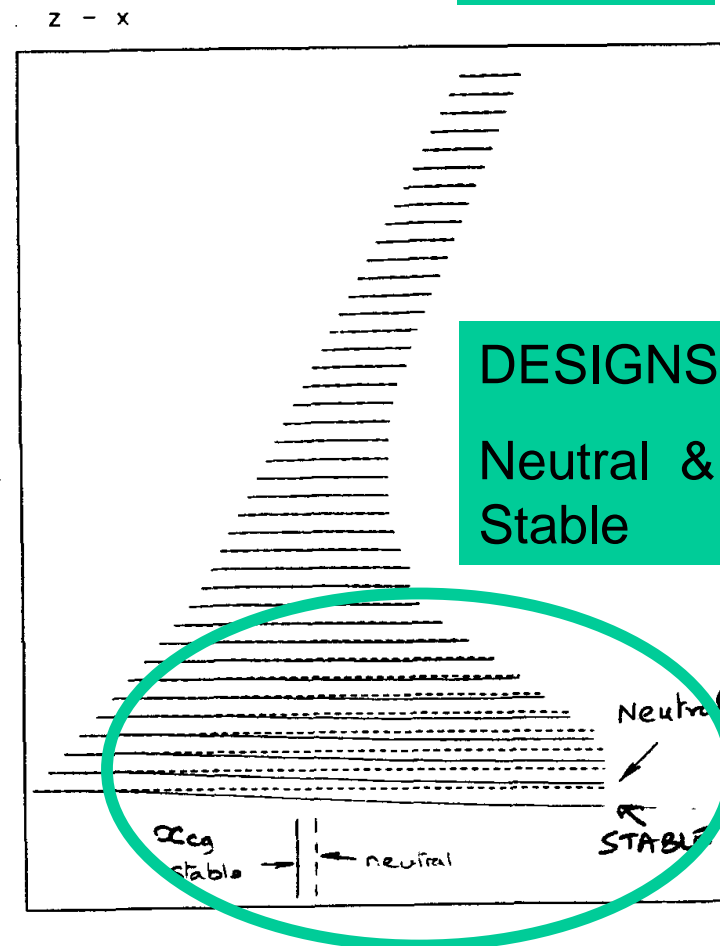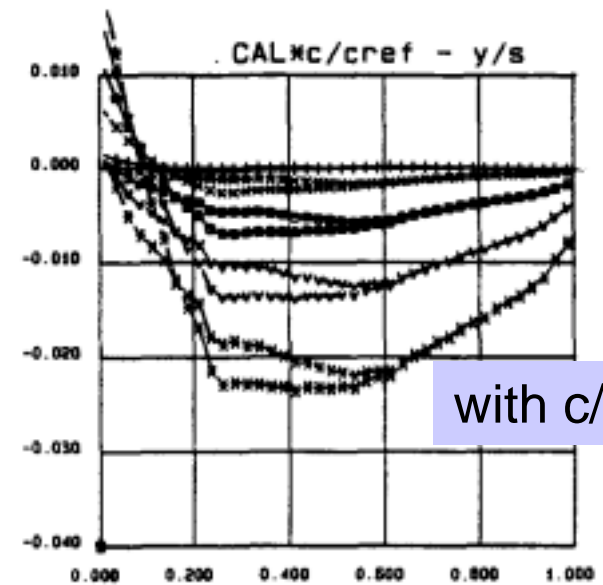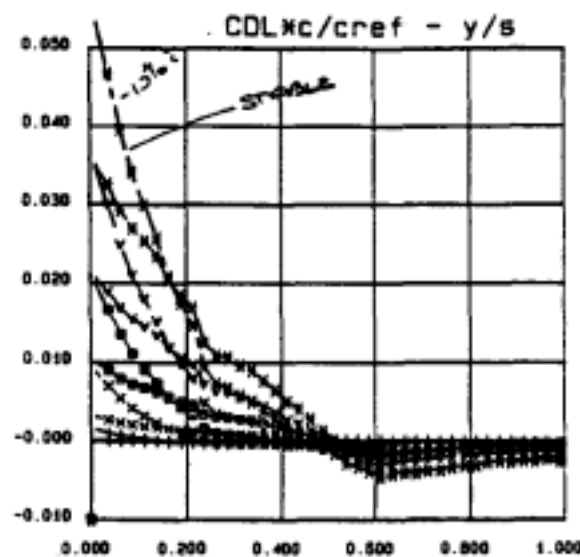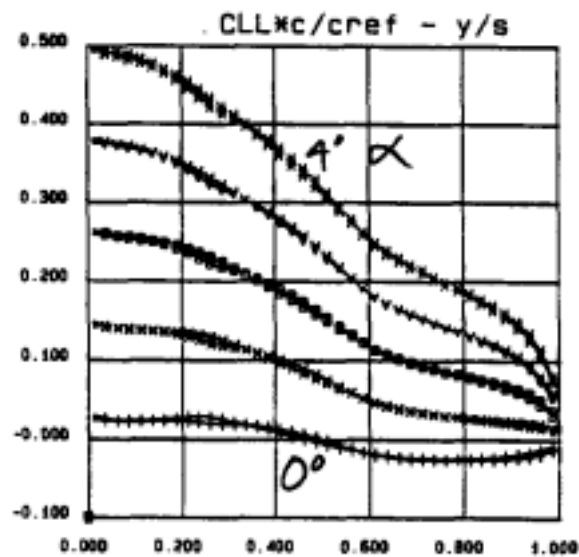
Note Twist Req'd

UNSTABLE

ASW -A1

FIG. 7 PLANFORM A1, DESIGNED CAMBER, SPANWISE LOADINGS WITHOUT c/c$_{av}$ FACTOR, STATIC MARGIN VARIES, 10%c$_{av}$ Stable, Neutral & 10% c$_{av}$ Unstable, Mach 0.8
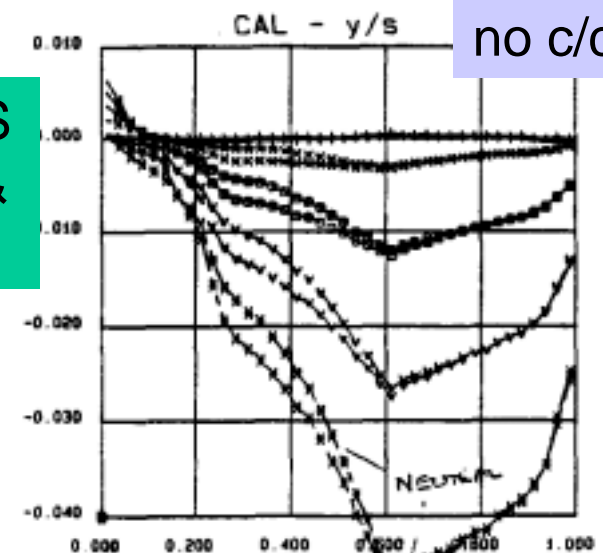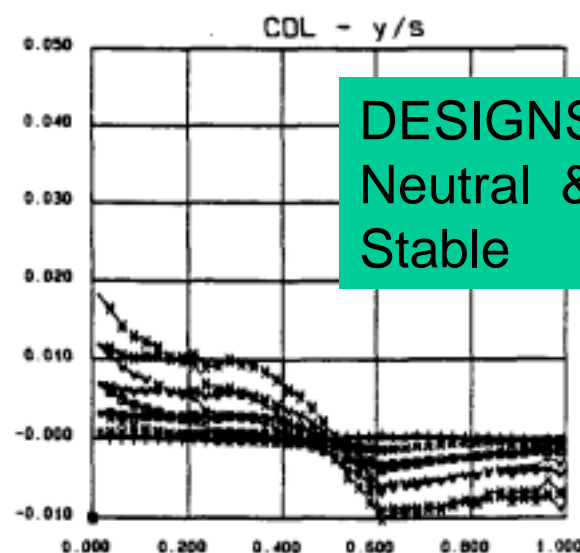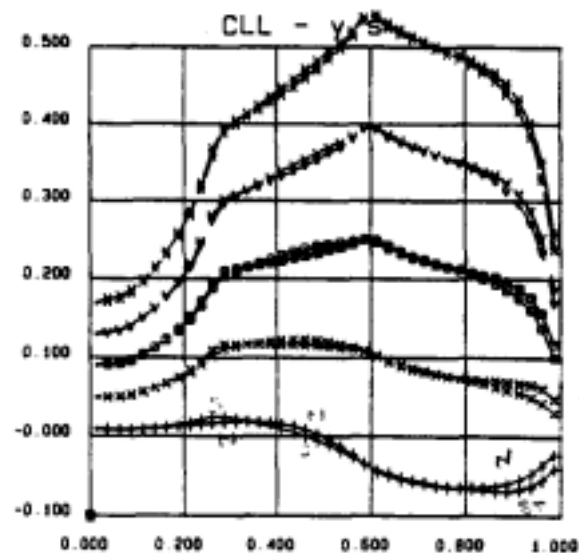
CL-alpha

CD - CL

Cm - CL
neutral
Stable

CA - CL

z - x
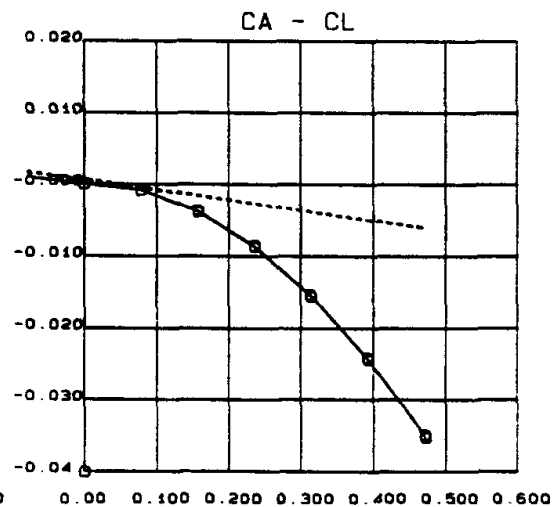
ASW -A1

DESIGNS
Neutral &
Stable

Neutral

STABLE

α_{cg} stable → neutral

Charts (top row, "with c/cref"):
- CLL*c/cref – y/s
- CDL*c/cref – y/s
- CAL*c/cref – y/s

Charts (bottom row, "no c/cref"):
- CLL – y/s
- COL – y/s
- CAL – y/s

Labels: A' α, 0°, STABLE, NEUTRAL

with c/cref
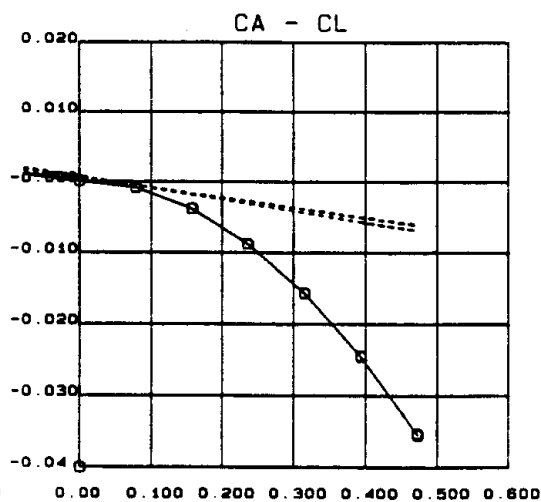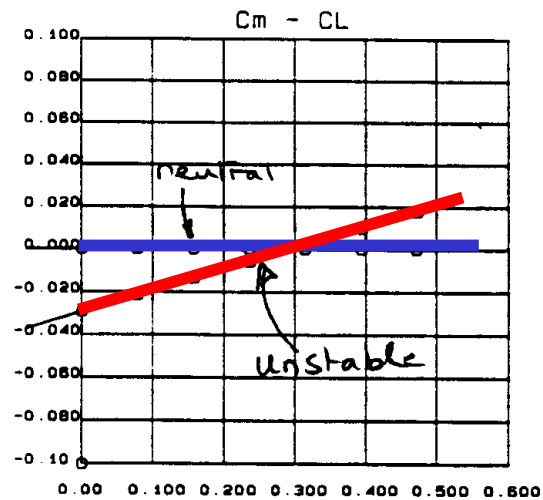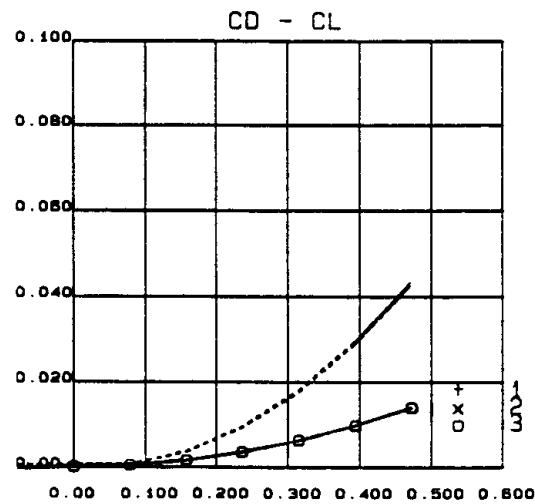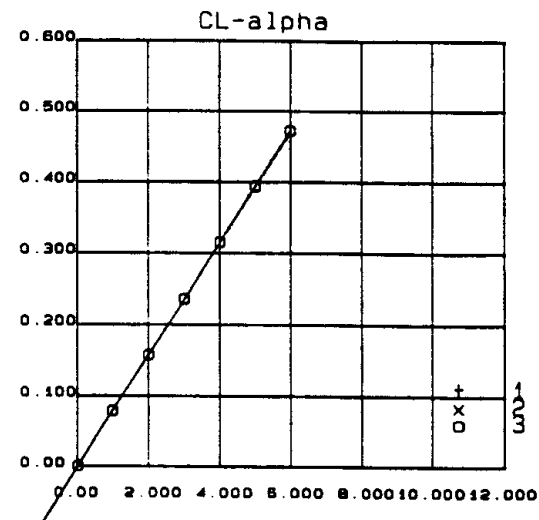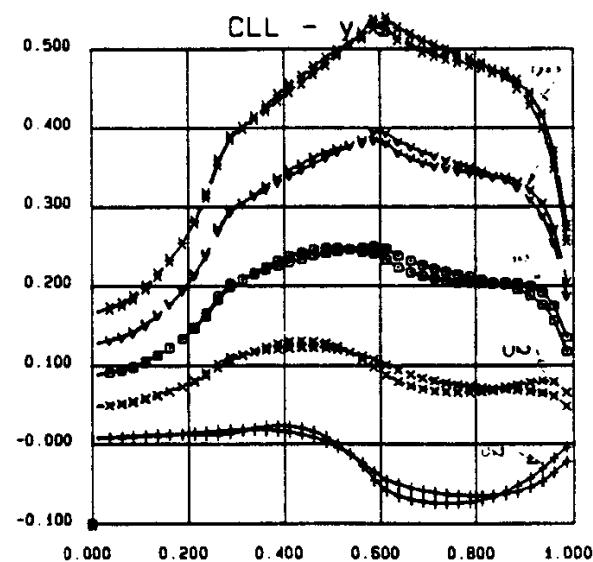
no c/cref

DESIGNS
Neutral &
Stable

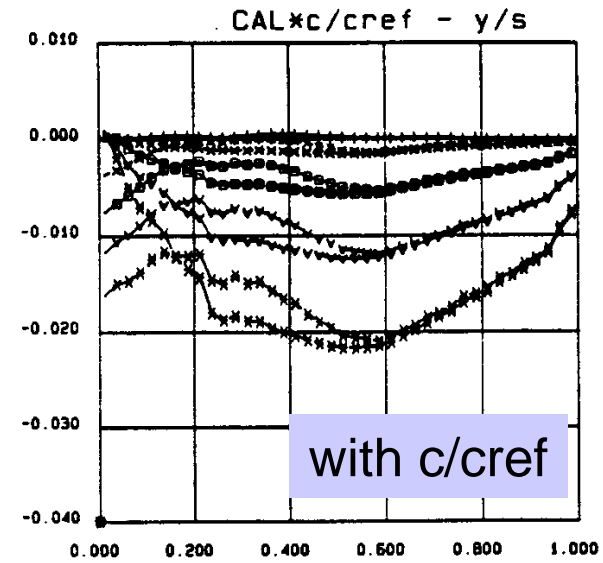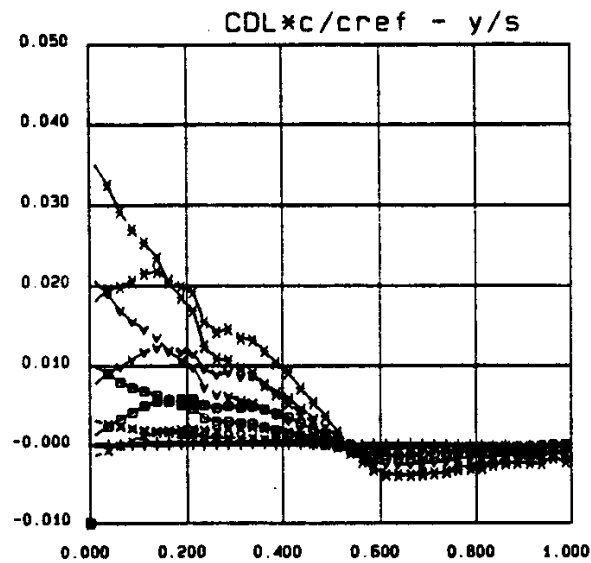ASW -A1 ... PLANFORM A1, COMPARING FORCES, DESIGNED CAMBER, SPANWISE LOADINGS, STATIC MARGIN VARIES, 10%c_{av} Stable, Neutral, Mach 0.8

CL-alpha

CD - CL

z - x

ASW -A1

Cm - CL

neutral

Unstable

CA - CL

DESIGNS

Neutral &
Unstable

Unstabl.

x_{cg}
neutral — Unstable — neutral

Top row plots: CLL*c/cref - y/s, CDL*c/cref - y/s, CAL*c/cref - y/s

with c/cref

no c/cref

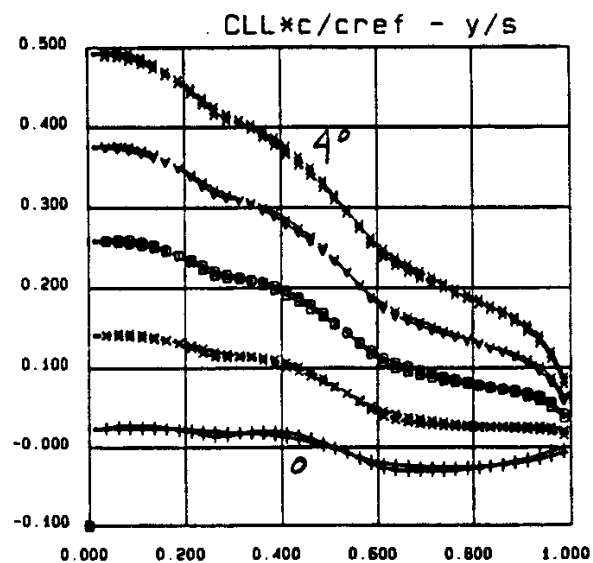DESIGNS Neutral & Unstable

Bottom row plots: CLL - y/s, CDL - y/s, CAL - y/s
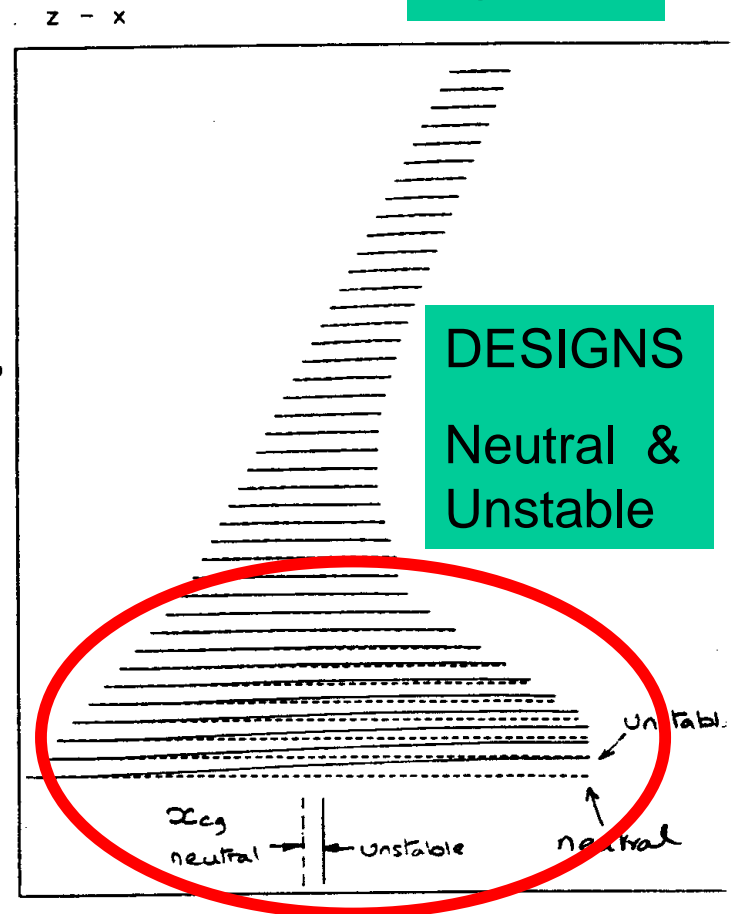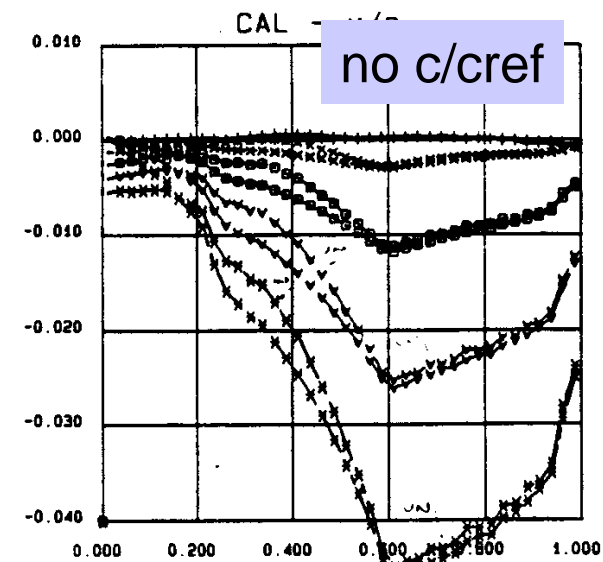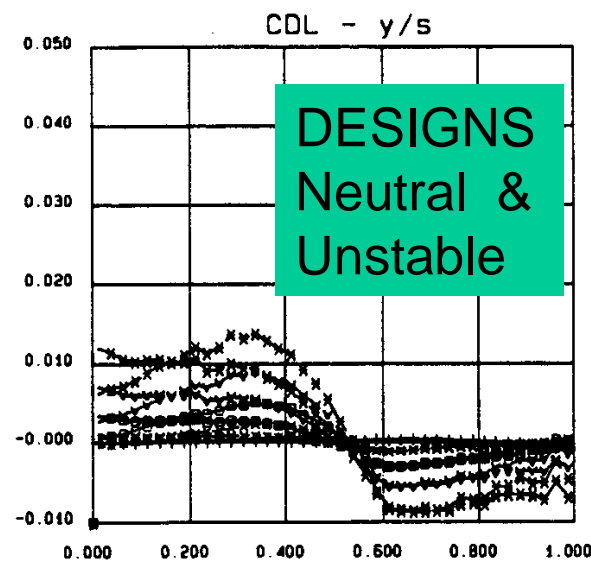
ASW -A1

PLANFORM A1, COMPARING FORCES, DESIGNED CAMBER, SPANWISE LOADINGS, STATIC MARGIN VARIES, 10%c_{av} Unstable, Neutral, Mach 0.8
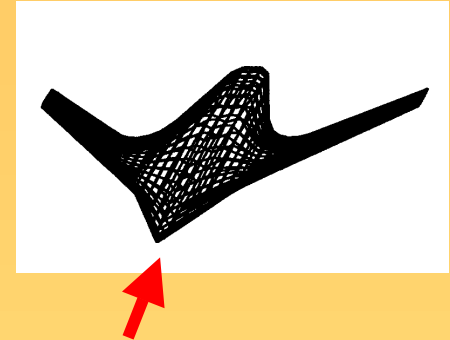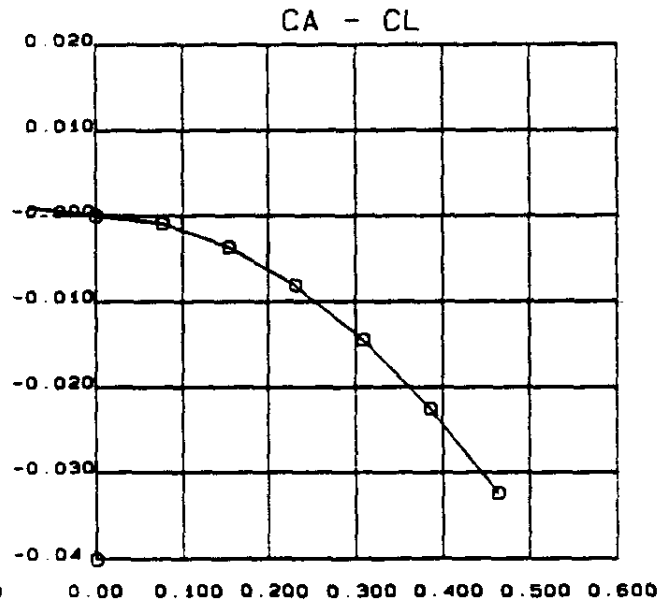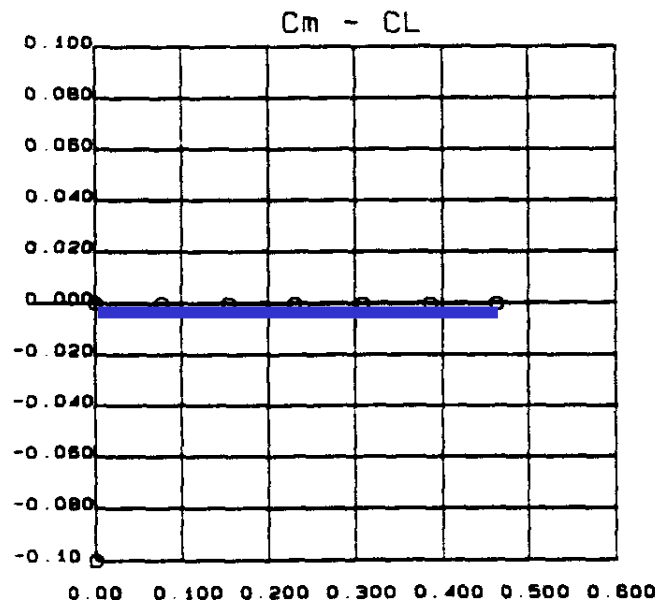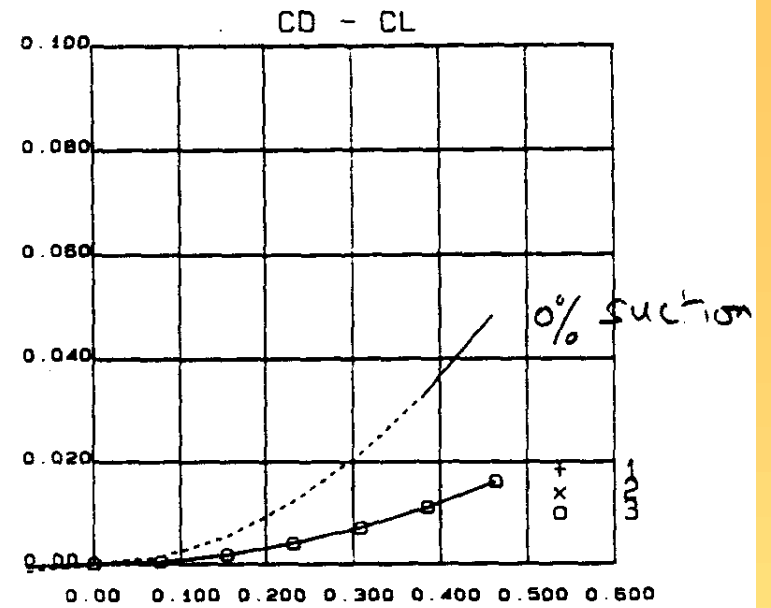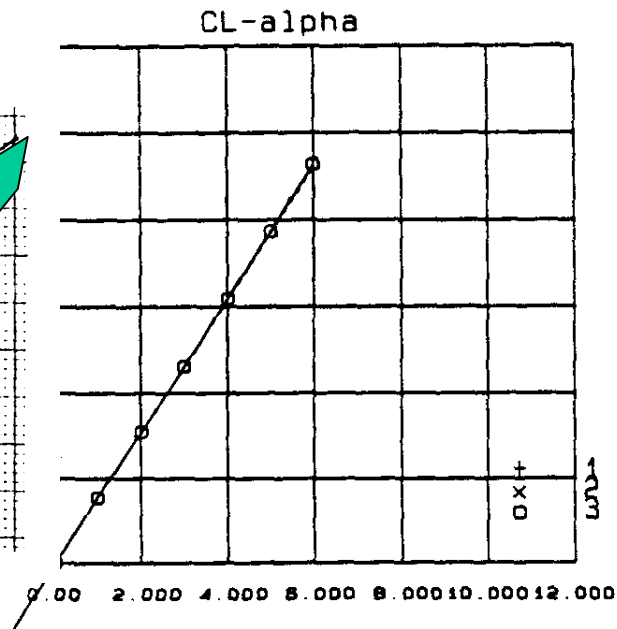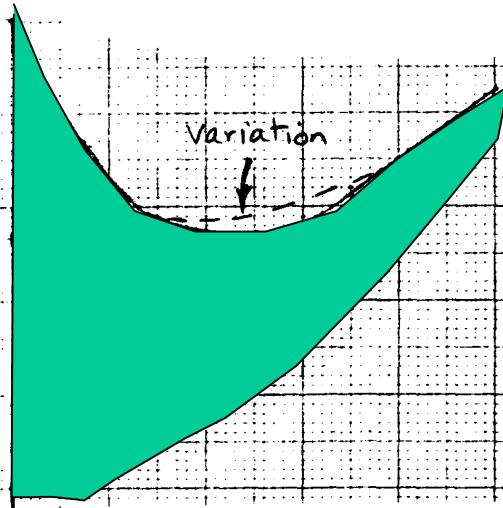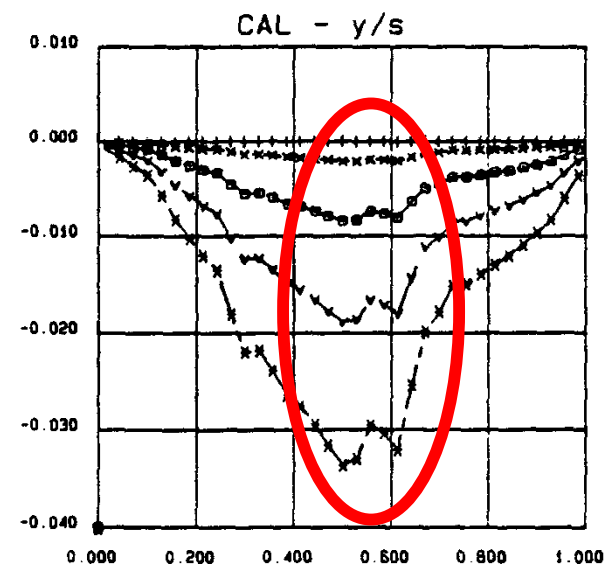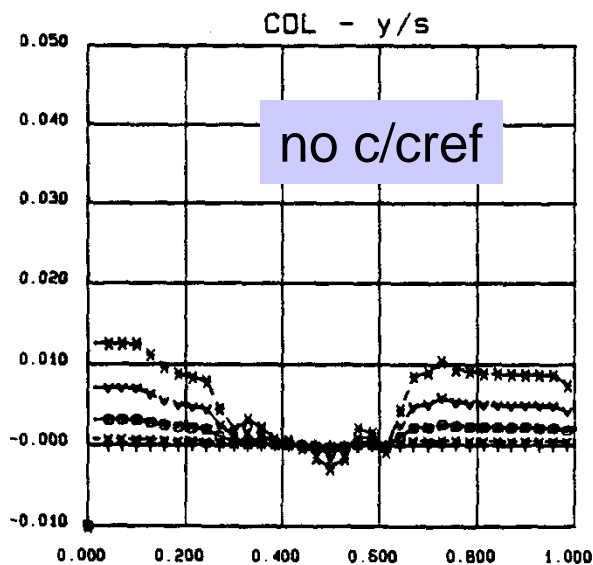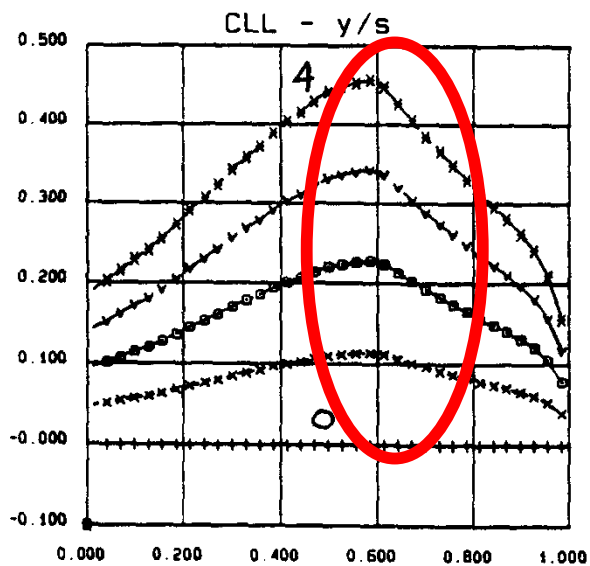
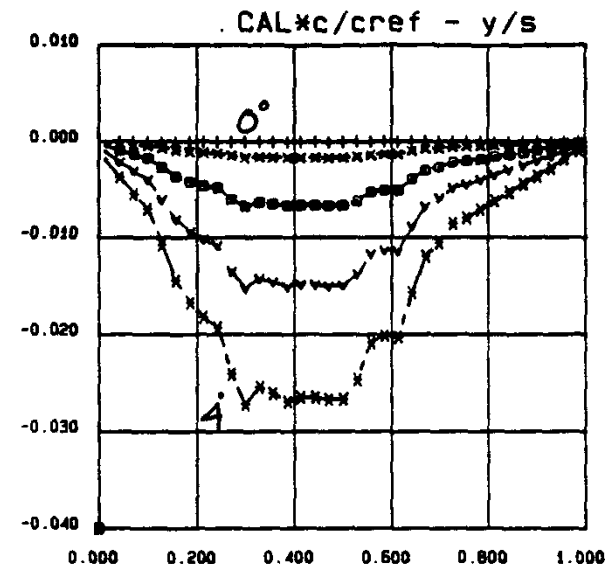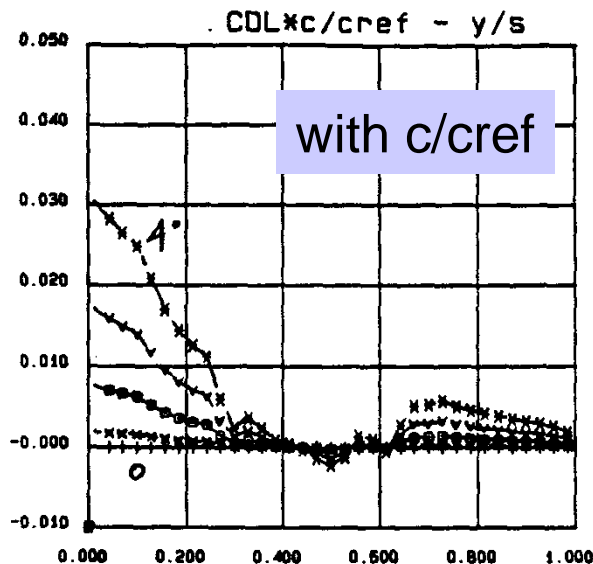# Longitudinal

- Short Moment Arms, Low Pitch Inertia
- go for longer inner wing (fuselage !)
  - thickness important at root
- Cabin floor angle restriction
- Twist required, increases for stable flight
  - affects CD0
- Neutral pt. shifts forward for low speed 3%, Trim!
- "armpit" control "fights" "tip" control, moment arms geometry cuts effectiveness by 1/2
- Need to continue Planform Work

CL-alpha

CD – CL

0% suction

Cm – CL

CA – CL

About
Neutral point

FSW -F1 , PLANAR, FORCES & MOMENTS, Mach 0.8

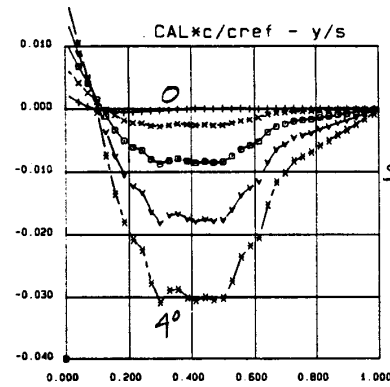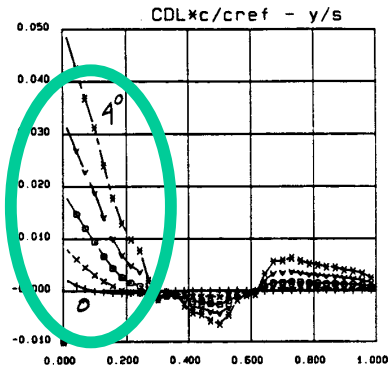CLL×c/cref – y/s   COL×c/cref – y/s   CAL×c/cref – y/s

with c/cref

CLL – y/s   COL – y/s   CAL – y/s
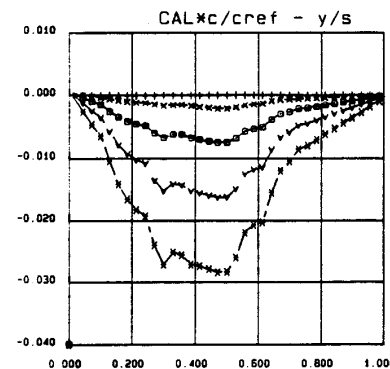
no c/cref
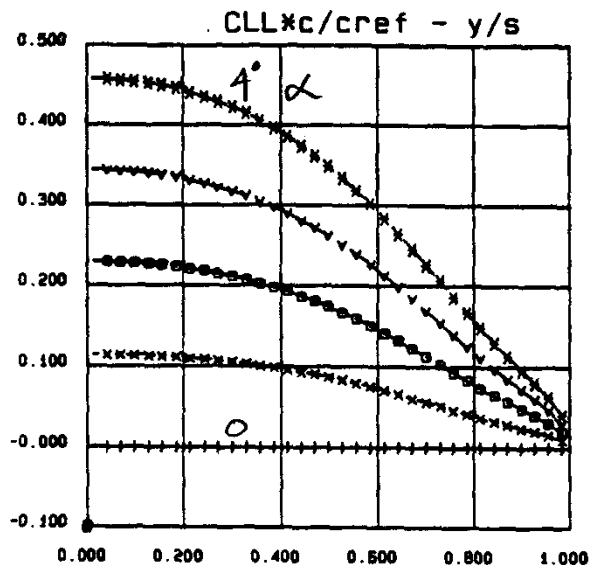
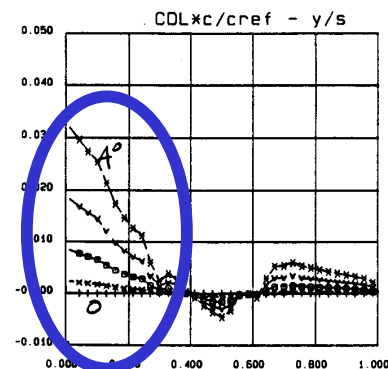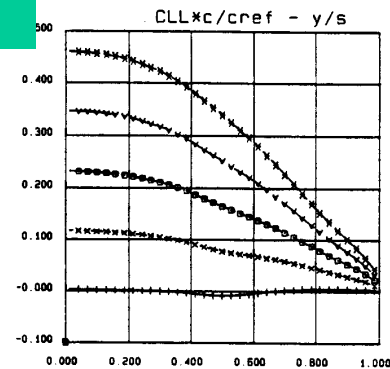FSW -F1   , PLANAR, SPANWISE LOADINGS WITH AOA VARIATION, LIFT, DRAG & AXIAL FORCE, Mach 0.8
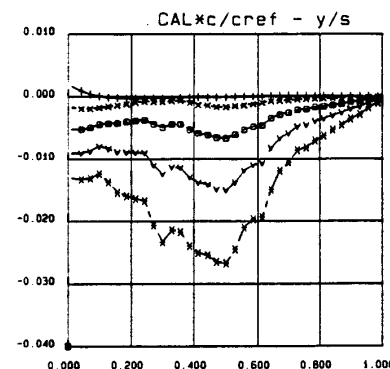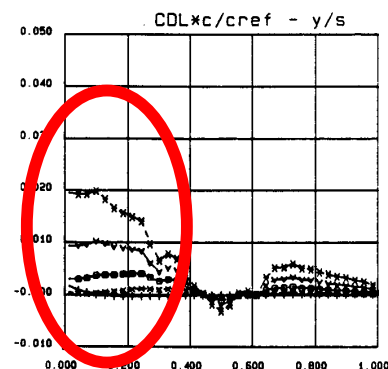
DESIGNED with c/cref
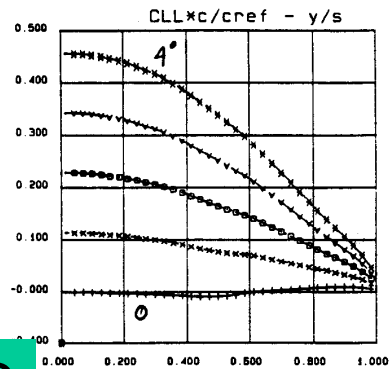
STABLE
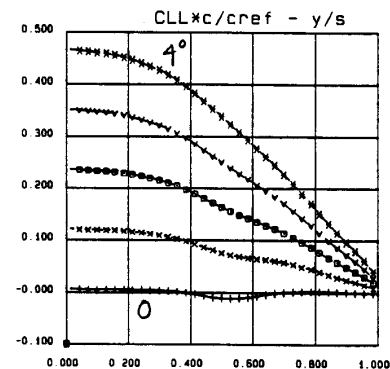
NEUTRAL

UNSTABLE

FSW -F1

PLANFORM F1, DESIGNED CAMBER, SPANWISE LOADINGS WITH c/c$_{av}$
FACTOR, STATIC MARGIN VARIES, 10%c$_{av}$ Stable, Neutral & 10% c$_{av}$ Unstable, Mach 0.8

FSW -F1

PLANFORM F1, DESIGNED CAMBER, SPANWISE LOADINGS WITHOUT c/c$_{av}$
FACTOR, STATIC MARGIN VARIES, 10%c$_{av}$ Stable, Neutral & 10% c$_{av}$ Unstable, Mach 0.8

DESIGNS
Neutral &
Stable

CL-alpha

CD - CL

Cm - CL

neutral

stable

CA - CL

z - x

x_{cg}

stable →   ← neutral

Stable

CLL*c/cref - y/s — **CDL*c/cref - y/s** — **CAL*c/cref - y/s**

with c/cref

no c/cref

DESIGNS
Neutral &
Stable

CLL - y/s — **CDL - y/s** — **CAL -**

FSW -F1   PLANFORM F1, COMPARING FORCES, DESIGNED CAMBER, SPANWISE LOADINGS, STATIC MARGIN VARIES, 10%c_{av} Stable, Neutral, Mach 0.8

CL-alpha

CD – CL

DESIGNS
Neutral &
Unstable

z – x

Cm – CL

unstable

neutral

CA – CL

x_cg

neutral → ← unstable

neutral

CLL×c/cref − y/s   **CDL×c/cref − y/s**   **CAL×c/cref − y/s**

with c/cref

CLL − y/s   **CDL − y/s**   **CAL − y/s**

no c/cref
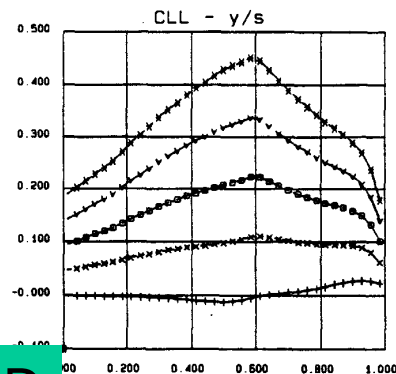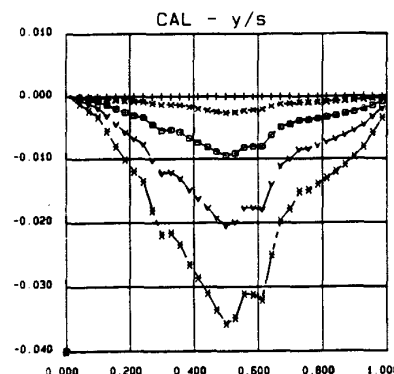
DESIGNS Neutral & Unstable

FSW -F1   PLANFORM F1, COMPARING FORCES, DESIGNED CAMBER, SPANWISE LOADINGS, STATIC MARGIN VARIES, 10%c_{av} Unstable, Neutral, Mach 0.8

DESIGNS
Neutral &
Unstable

Cabin
floor
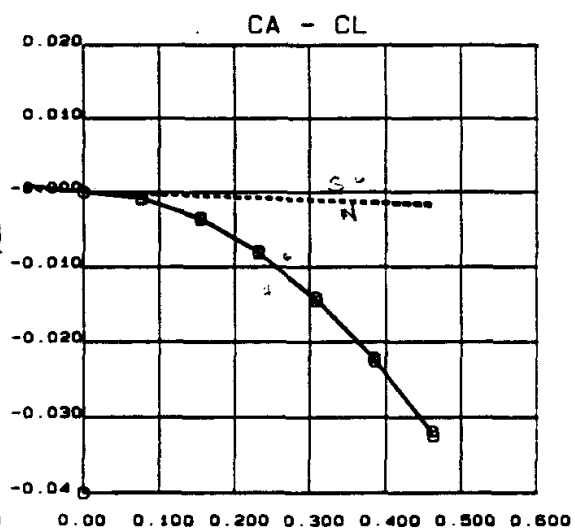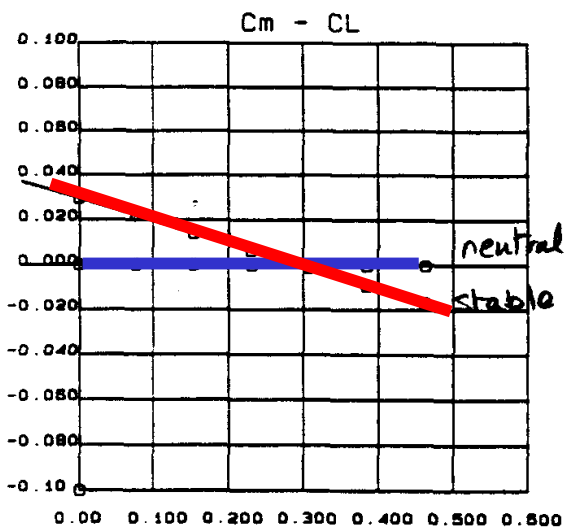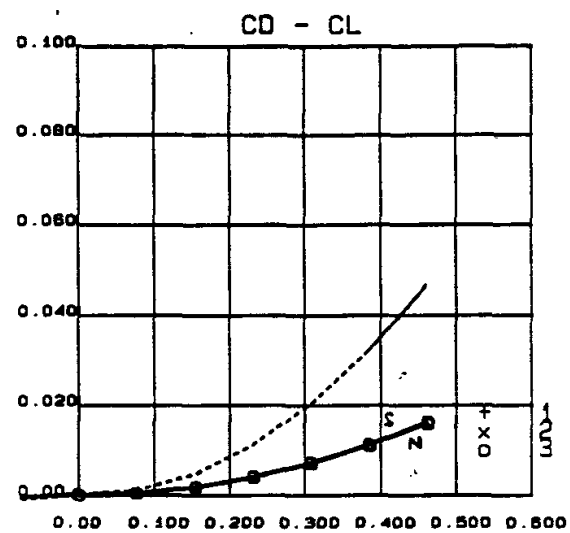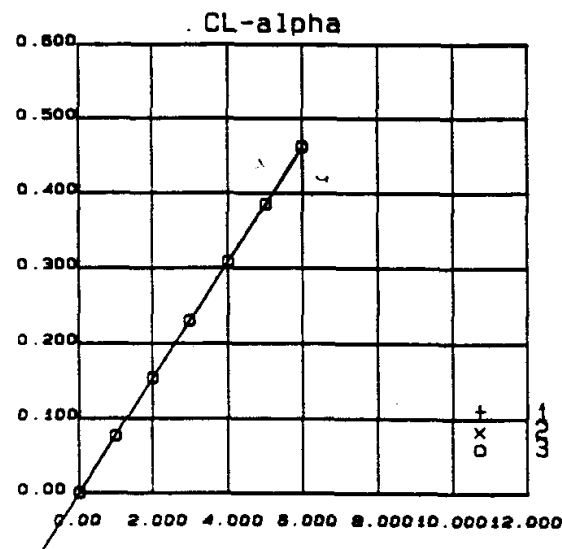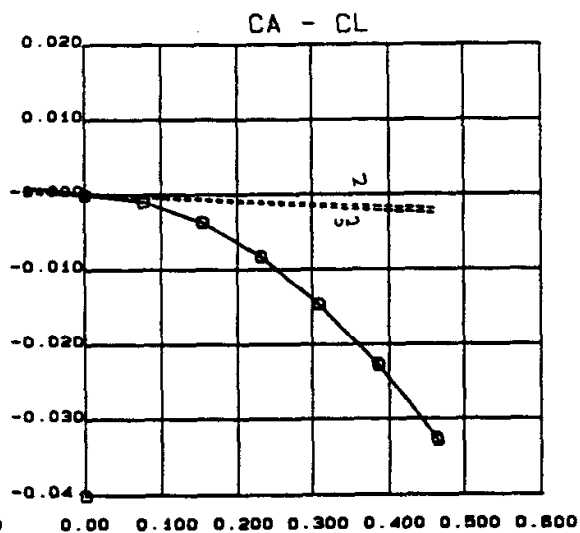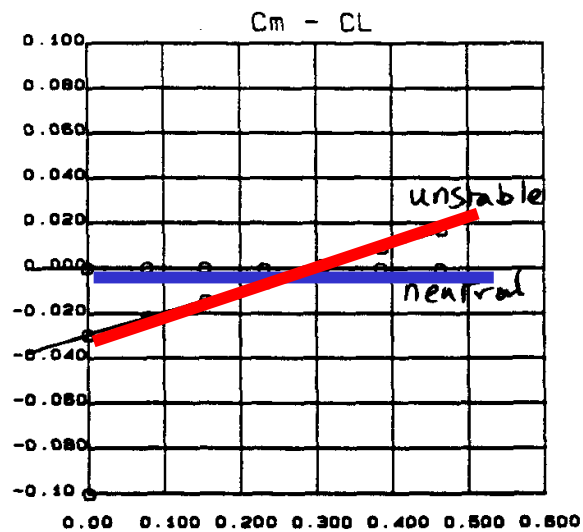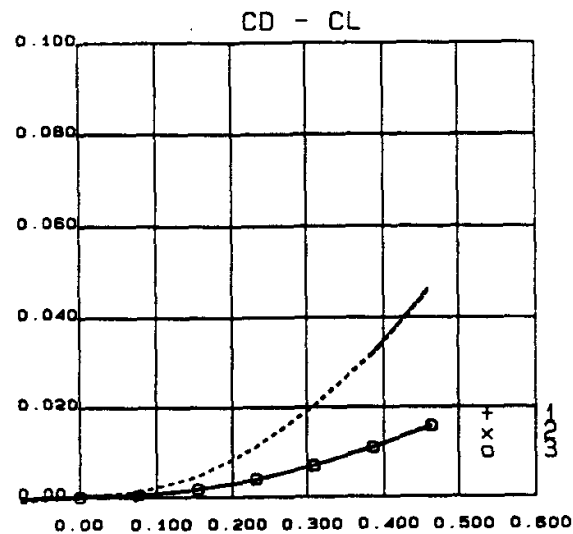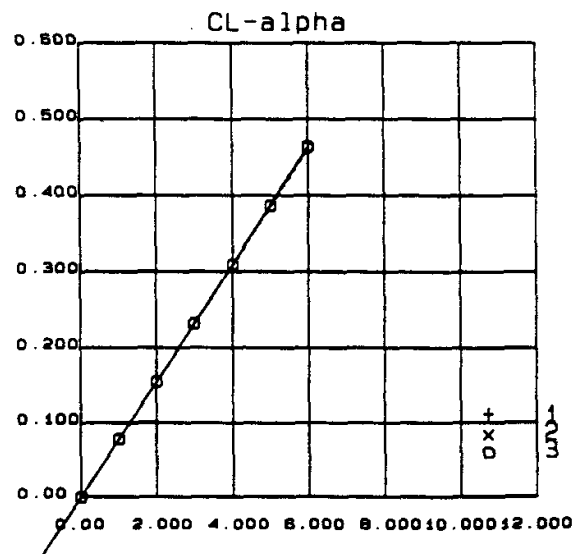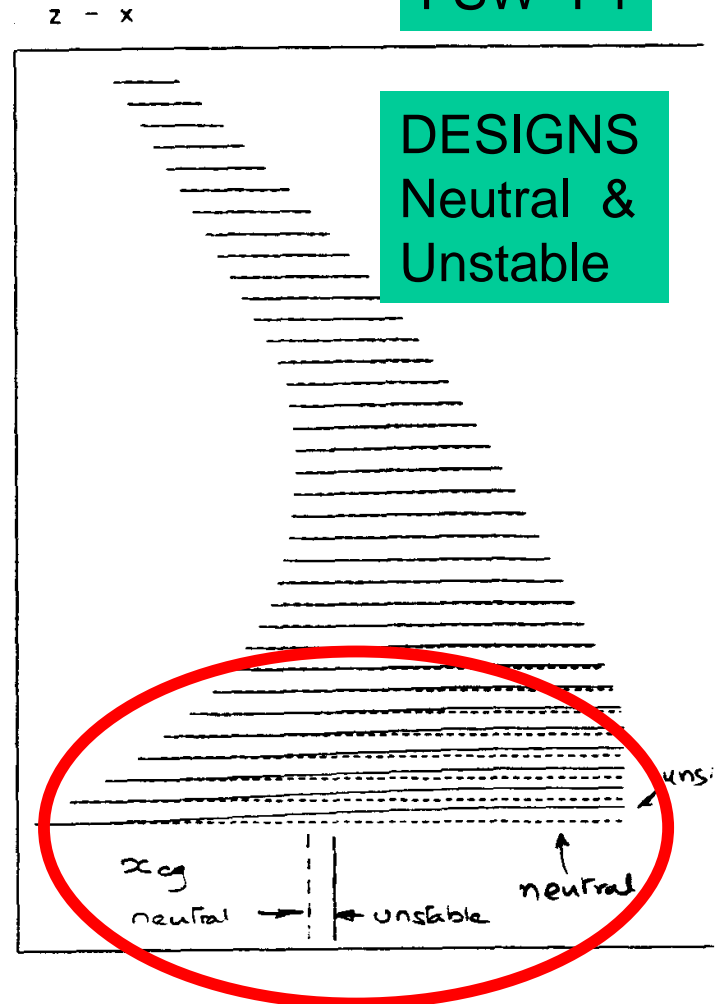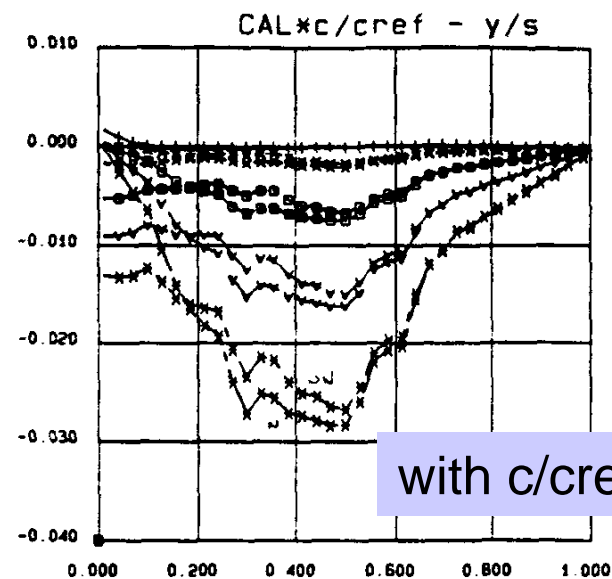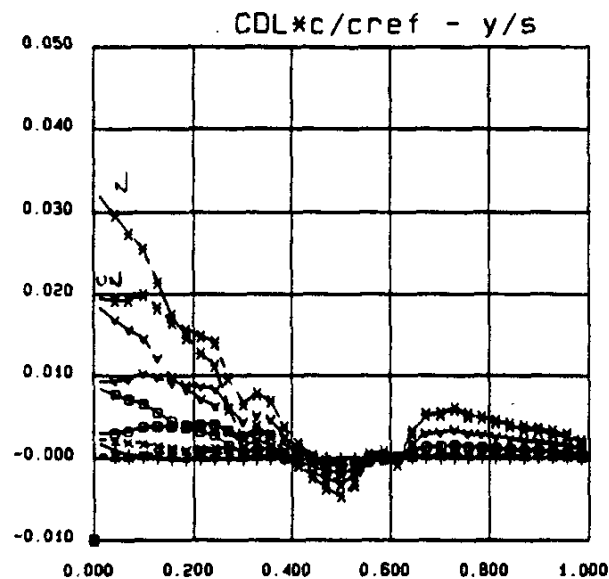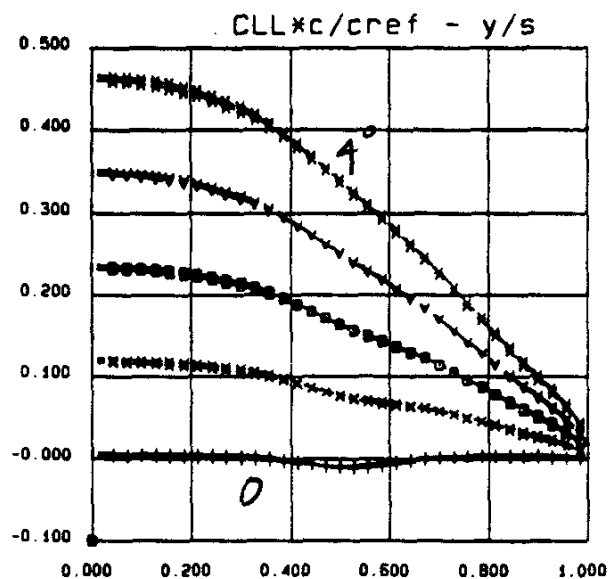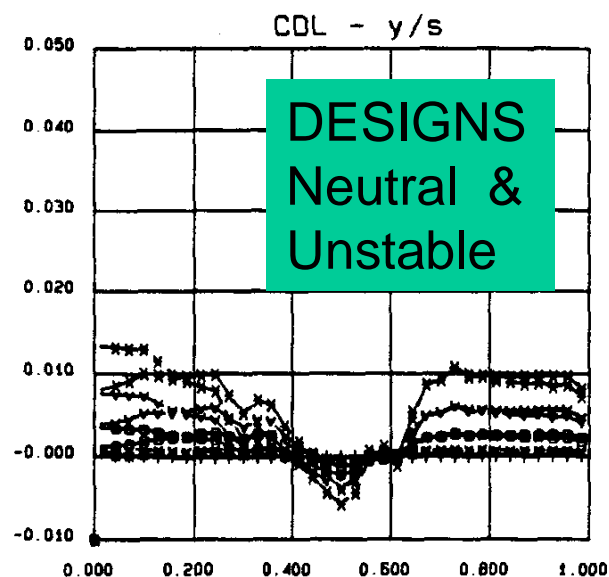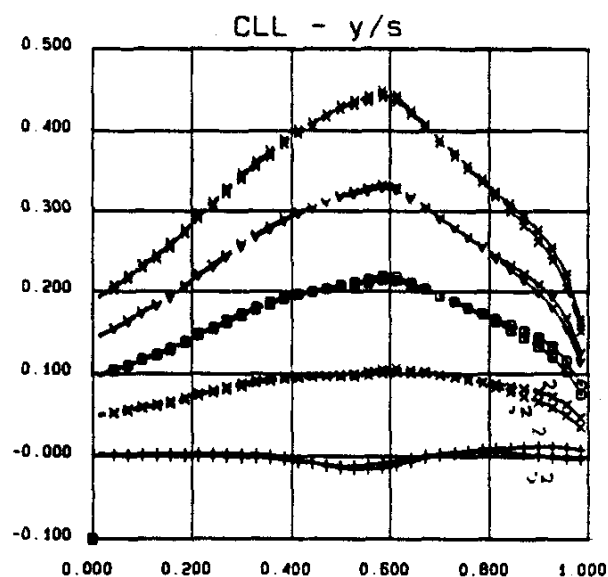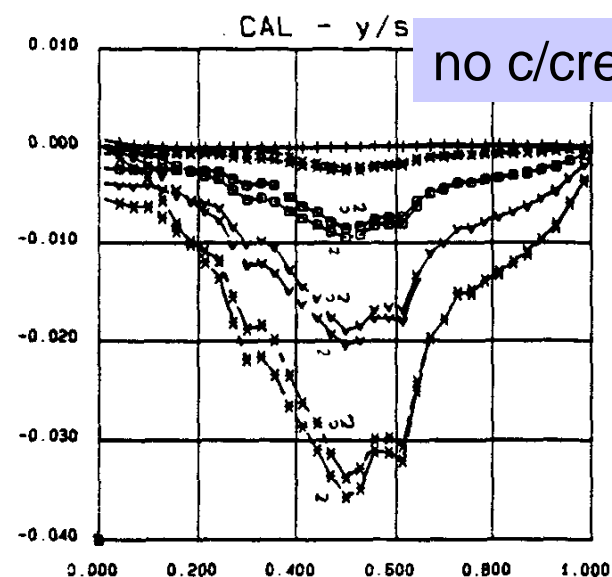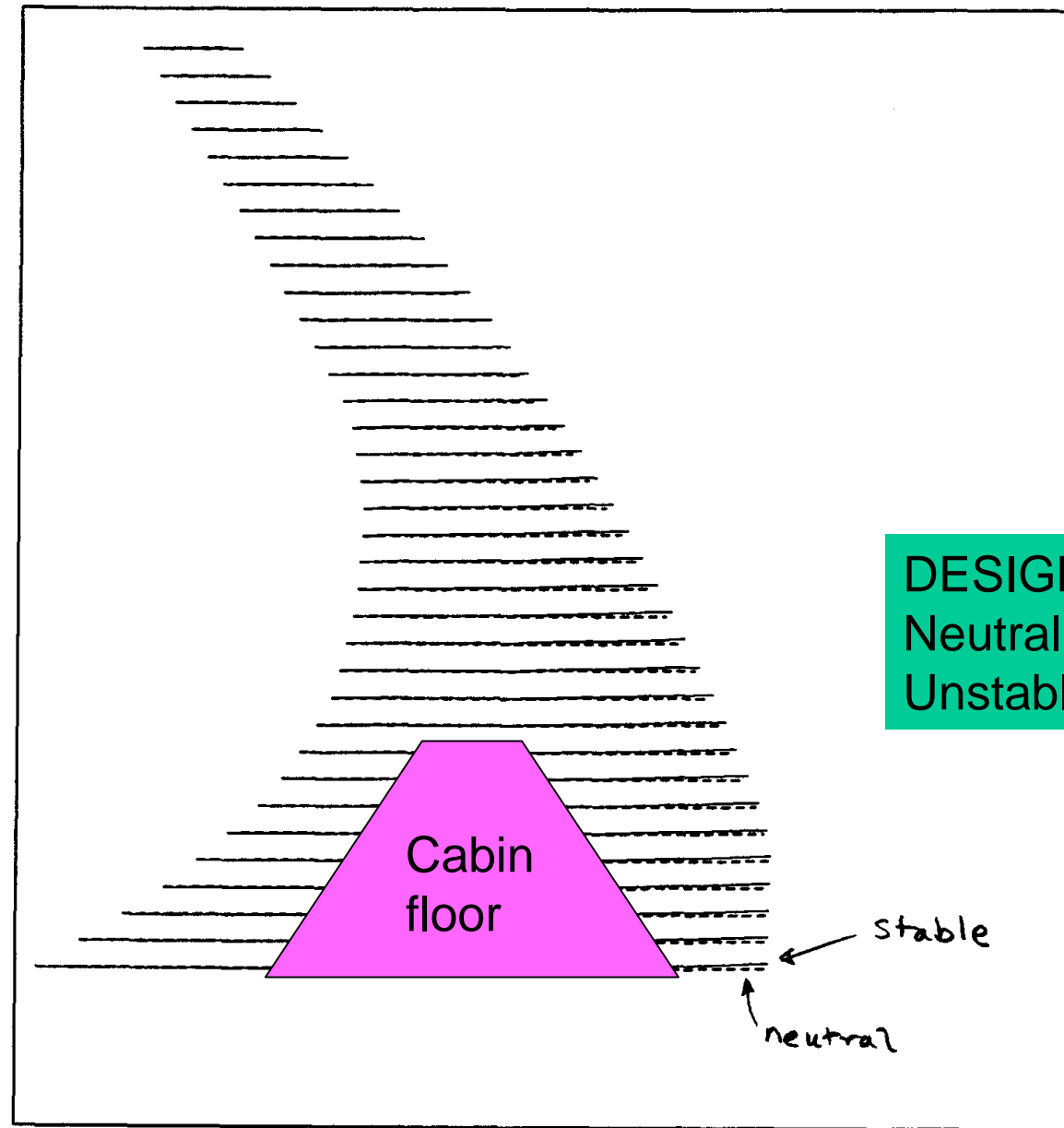
stable

neutral

FSW -F1

, COMPARING DESIGNED CAMBER, STATIC MARGIN VARIES, 0%
Neutral & 10%c_{av} Unstable, Mach 0.8

Design Inferences

- Stable Static margin leads to TE down (higher local Incidence) camber.

- Camber & Twist can be controlled over regions

Aft- Swept Wings, Usual

- Outer Wings are more heavily loaded
  - which have to be off-loaded for trim
  - leading to aero centre shifts off-design.
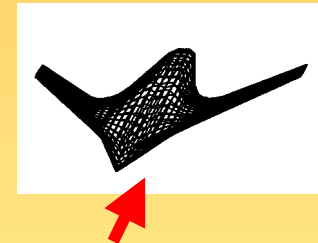
Forward- Swept Wings, A Contender

- Outer Wing are lightly loaded, more in sympathy with planform sweep & chord as well as root BM

- Capitalise on FSW laminar flow

- With Aero-elastic tailoring, structural divergence should be less of a problem on wings of 9% t/c, X-29 was 4% thick.
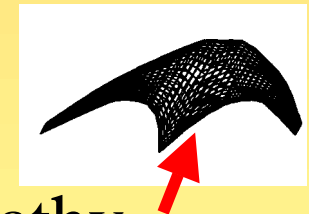
Transports, Directional, Lateral

- Critical - One Engine-Off during take-off or at low-speeds (30 kt cross-wind). Large Aircraft, 80m span
- Ability to hold a 10 deg heading at 75% control power
- Vertical fins exist, low moment arms.
- Can't have Anhedral
- Balancing by Split Ailerons produces drag
  - Low L/D, Climb Gradient affected
- Rudders+Split ailerons
- Initially, side-force dominates before yawing effects come in (high inertia in yaw)
  - No more than 30 m "drift" permitted on runways
- Continual Research needed.

Lateral Characteristics

Dihedral / Anhedral introduced over outer 70% semi-span, PRELIMINARY

$C_{l\beta}/°$

0.002

0.0

-0.002

-0.004

-0.006

0.1   0.3   0.4 C_L 0.5   0.6   0.7   0.8

FSW-FI $\Gamma = -4°$

FSW-FI $\Gamma = +4°$

ASW-AI $\Gamma = -4°$

ASW-AI $\Gamma = +4°$

Clß based on semi-span, MACH 0.2
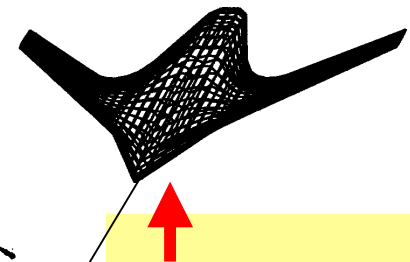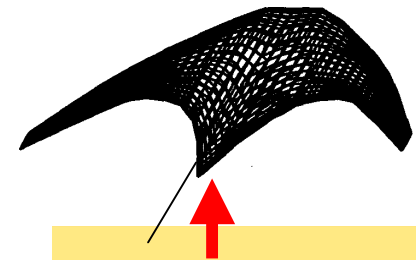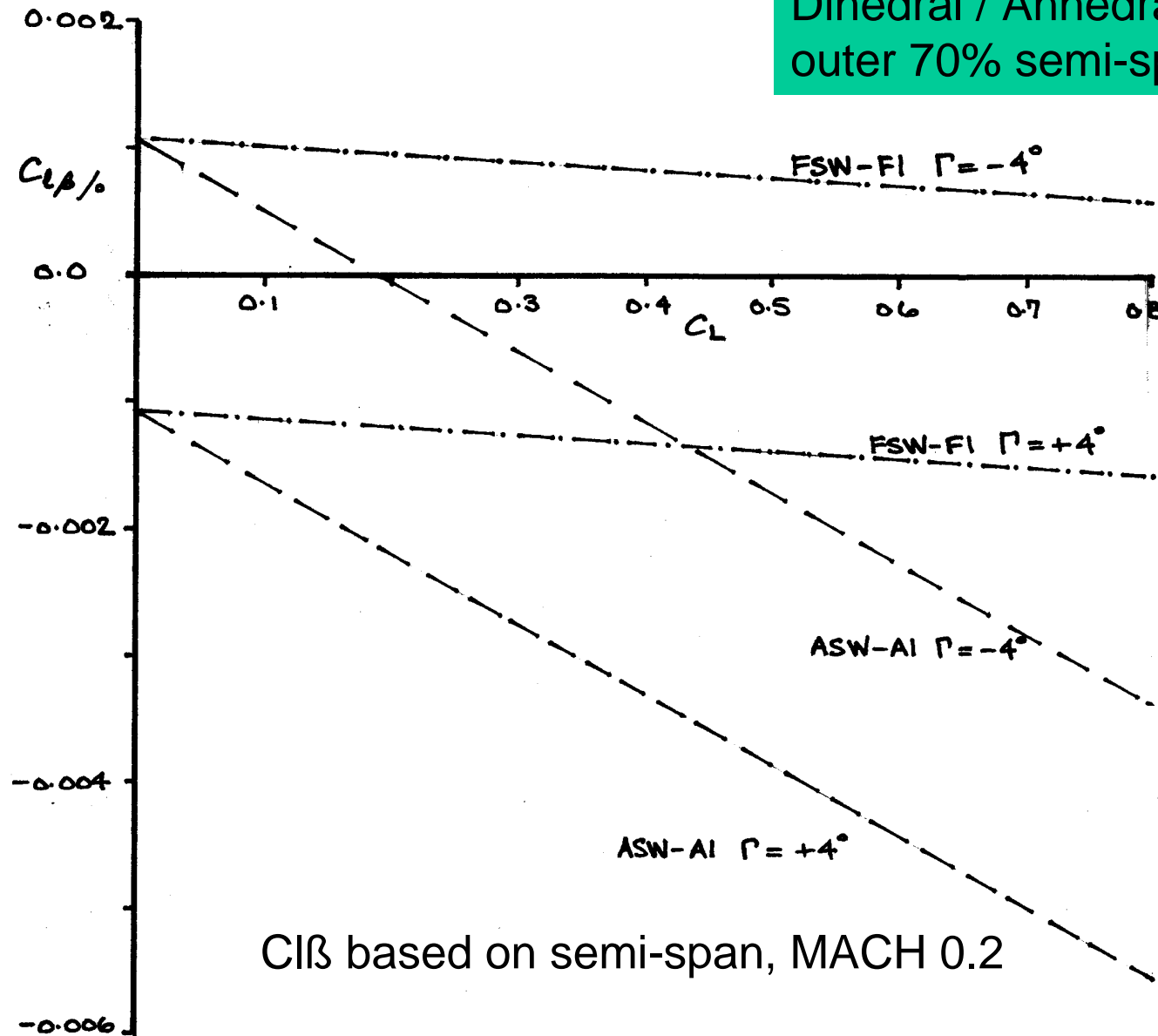
Military Lateral, Directional

- B-2 (No Vertical fins) appears Directionally unstable with Active Control system and sophisticated side-slip measurement

- Adequate Thrust available on Military Aircraft
- Thrust can be deflected / vectored !
- Split Ailerons / Drag rudders for Yaw moment
- Clß at low speeds, Dihedral/Anhedral Effect
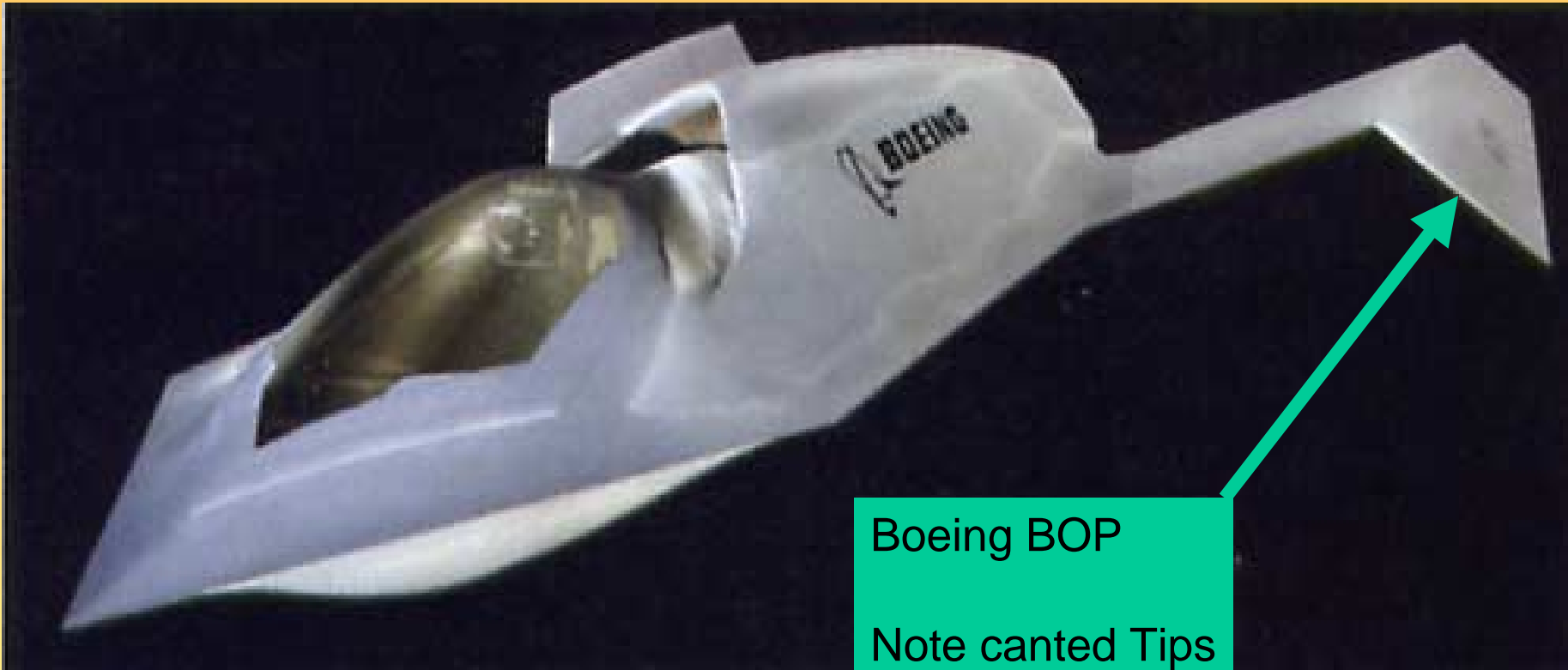
Boeing BOP

Note canted Tips
Stealth + Clß !
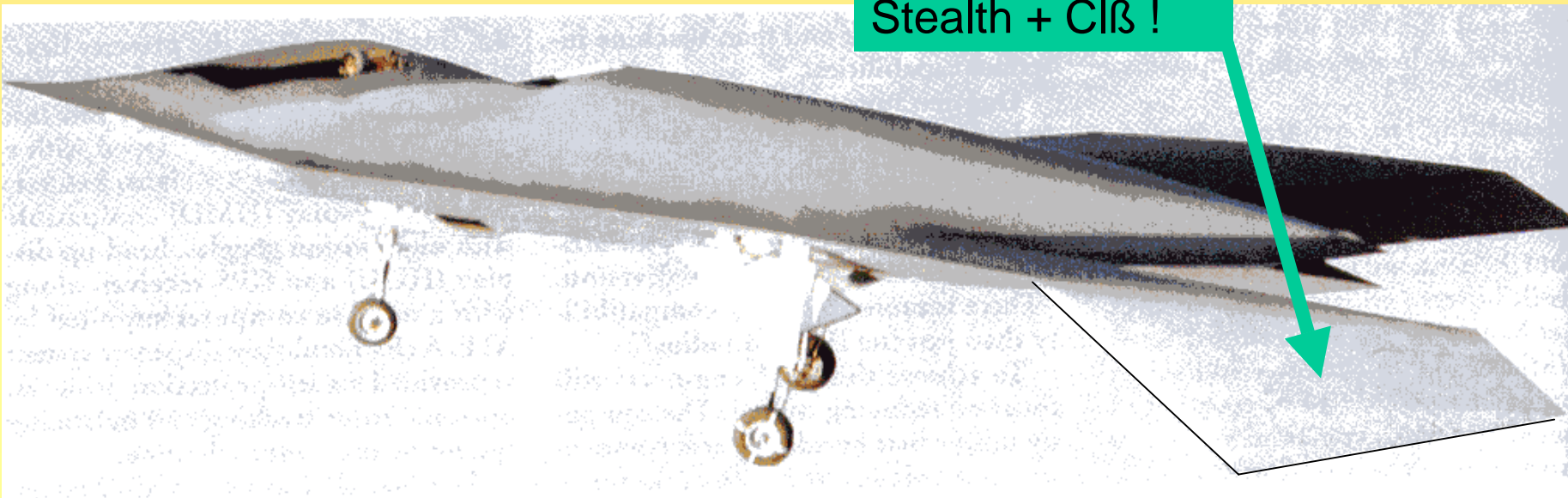
Future Work

- More Parametric Studies including FSW
- Combining with Euler for detailed Transonics
- Low-Speed pitch trim using LEF / TEF
- Control Requirements, small moment arms
- Roll & Yaw Coupling, Fins, Dutch Roll
- Off-design effects
- Intakes / Propulsion

Concluding Remarks

- Revival of Interest in Flying Wings for Military & Civil, different set of Constraints summarised, e.g. Low CL

- Appreciation of Solvers, Linear Theory, Euler
  - Understanding & Quick turn-around needed

- Strategy: Appropriate Solvers with Stability Constraints

- Aft- & Forward- swept planforms Designed & studied with lifting surf. theory (Mach & Re. & Attained thrust) ts

- Capitalise on FSW laminar flow

- With Aero-elastic tailoring, structural divergence should be less of a problem 9% t/c wings (X-29 was 4% t/c).

- Preliminary work on Laterals, FSW permits Dihedral

*** Thank You for Listening ***

Barely touched the surface of this vast subject, plenty more to do!

There are Experts in the Audience

Shall we try Comments and Discussion

****